NASA CR-357

EVALUATION OF FASTENERS AND FASTENER MATERIALS FOR SPACE VEHICLES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This report was prepared by the Contract Research Department, SPS Laboratories, Standard Pressed Steel Co., Jenkintown, Pennsylvania. The work was initiated under Contract No. NAS 8-11125 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. It was administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Engineering Materials Division of the George C. Marshall Space Flight Center with Robert R. Rowe acting as Project Manager.

Appreciation is gratefully acknowledged for the cooperation extended to SPS Laboratories by the NASA Contractors, NASA installations, and fastener manufacturers who contributed their time and information for the successful completion of the survey. In addition, SPS acknowledges the contribution of Al Alman of the Townsend Co. (Cherry Rivet Division) and Glenn Money of National Screw Co. for the use of their equipment which enabled SPS to evaluate Cherry Rivets and Jo Bolts.

ABSTRACT

This document is the annual report for the year 1964 of Contract NAS 8-11125 for the "Evaluation of Fasteners and Fastener Materials for Space Vehicles". The objectives were to characterize those fasteners and materials most suitable at temperatures from -423°F (-253°C) to 1600°F (871°C). The effort was accomplished in the following four phases:

Phase I - Survey
Phase II - Fastener Evaluation
Phase III - Standard Fastener Tests
Phase IV - Potential High Strength Fastener Materials.

Phase I determined the space vehicle industry's present and future fastener requirements. The information obtained in the survey included present and future fastener materials, configurations, application and design criteria, testing and test methods, and fastener information and specifications.

As a result of the survey, twenty-one different classes of fasteners were selected for evaluation in Phase II. The fasteners consisted of variations in tension and shear bolts, blind bolts, structural rivets, and companion fasteners fabricated from within the specified base alloys of iron, nickel, titanium, and aluminum. The fasteners were tested to determine the following properties or exposure effects: tensile, shear, stress rupture, stress relaxation, nut reusability, nut vibration, corrosion resistance, effects of thermal cycling, and the effects of relaxation on mechanical properties.

Phase III is continuing to determine the unique tests required to characterize fasteners specifically for space vehicle applications.

Five alloys of iron, nickel, and titanium base were evaluated in Phase IV. The alloys were selected from the results of the survey on the basis of potential for high strength fastener applications, and expectant future usage. The alloys selected were Ti 1Al-8V-5Fe, 18 per cent nickel maraging steel (VascoMax 300), U-212, Inconel 718, and 25 per cent cold reduced Waspaloy.

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SECTION I

SUMMARY

The object of this program was to evaluate high strength fasteners and fastener materials, and to characterize those most suitable for space vehicle application at temperatures from -423°F (-253°C) to 1600°F (871°C). The effort was accomplished in the following four phases:

Phase I - Survey
Phase II - Fastener Evaluation
Phase III - Standard Fastener Tests
Phase IV - Potential High Strength Fastener Materials

Phase I was undertaken to determine the space vehicle industry's present and future fastener requirements. Information was contributed by the aerospace industry, consisting of NASA contractors, NASA installations, and fastener manufacturers. Also, a thorough search was made of available literature containing data on fasteners and potential fastener materials. The information derived from the survey included present and future fastener materials, configurations, applications and design criteria, testing and test methods, and fastener information and specifications. The information shows that the majority of structural applications involve shear loading with most engine applications involving tensile loading. A-286 alloy appears to be the most commonly used fastener material for cryogenic structural applications. Titanium alloys are being given more consideration in design due to the increased importance of strength to density ratio of fasteners. High temperature applications are relatively low with A-286 and Waspaloy alloys dominating the field.

As a result of the survey, twenty-one different classes of fasteners were selected for evaluation in Phase II, with the approval of the contracting officer's technical representative. The fasteners selected consisted of variations of tension and shear bolts, blind bolts, structural rivets, and companion fasteners fabricated from within the specific base alloys of iron, nickel, titanium, and aluminum. The fasteners were procured from the various fastener manufacturers supplying the aerospace industry.

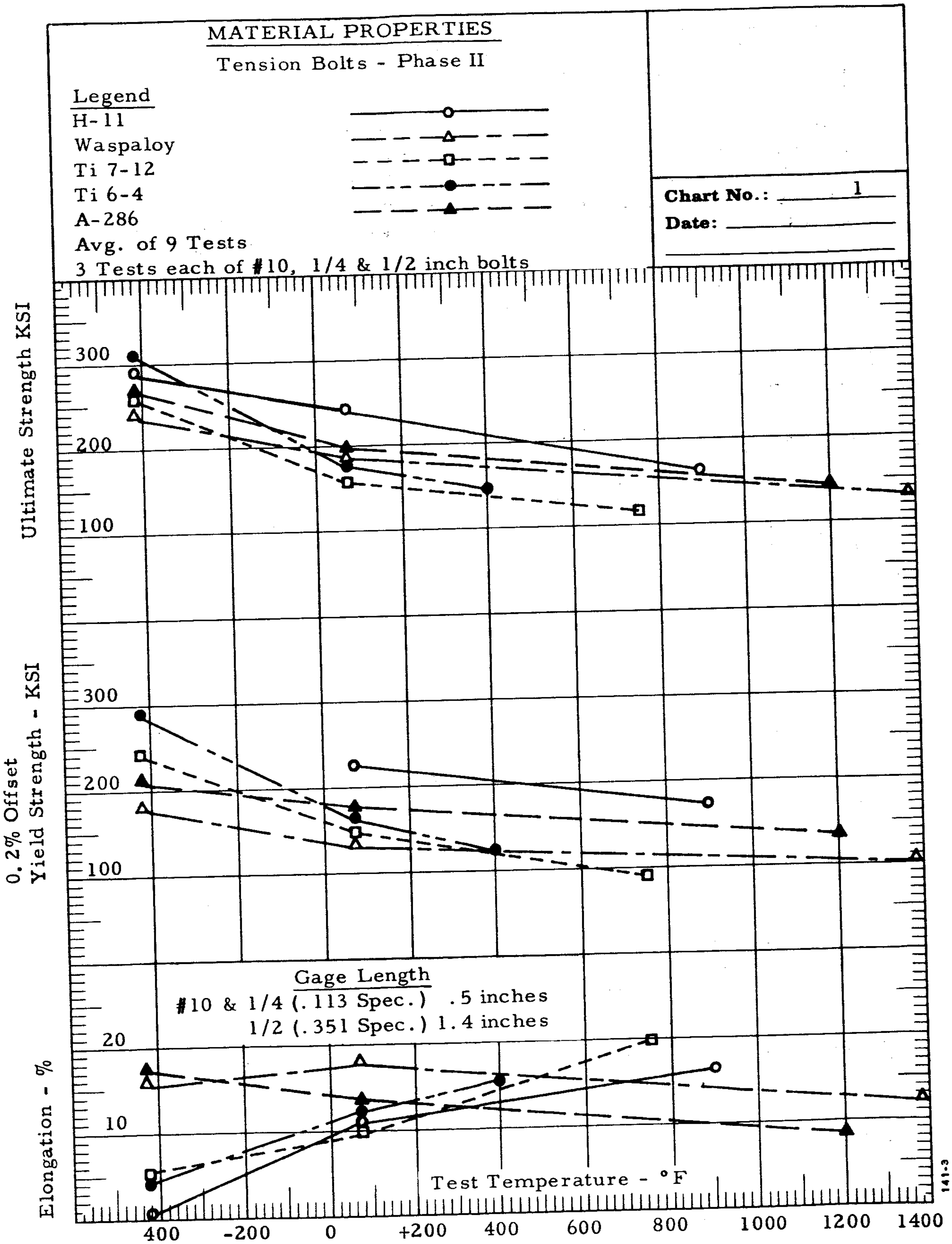
The evaluation developed usage and design data for the twenty-one different classes of fasteners, from -423°F to their respective maximum utilization temperatures. Tests included tensile, shear, stress rupture, stress relaxation, nut reusability, nut vibration, corrosion resistance, effects of thermal cycling, and the effects of relaxation on mechanical properties.

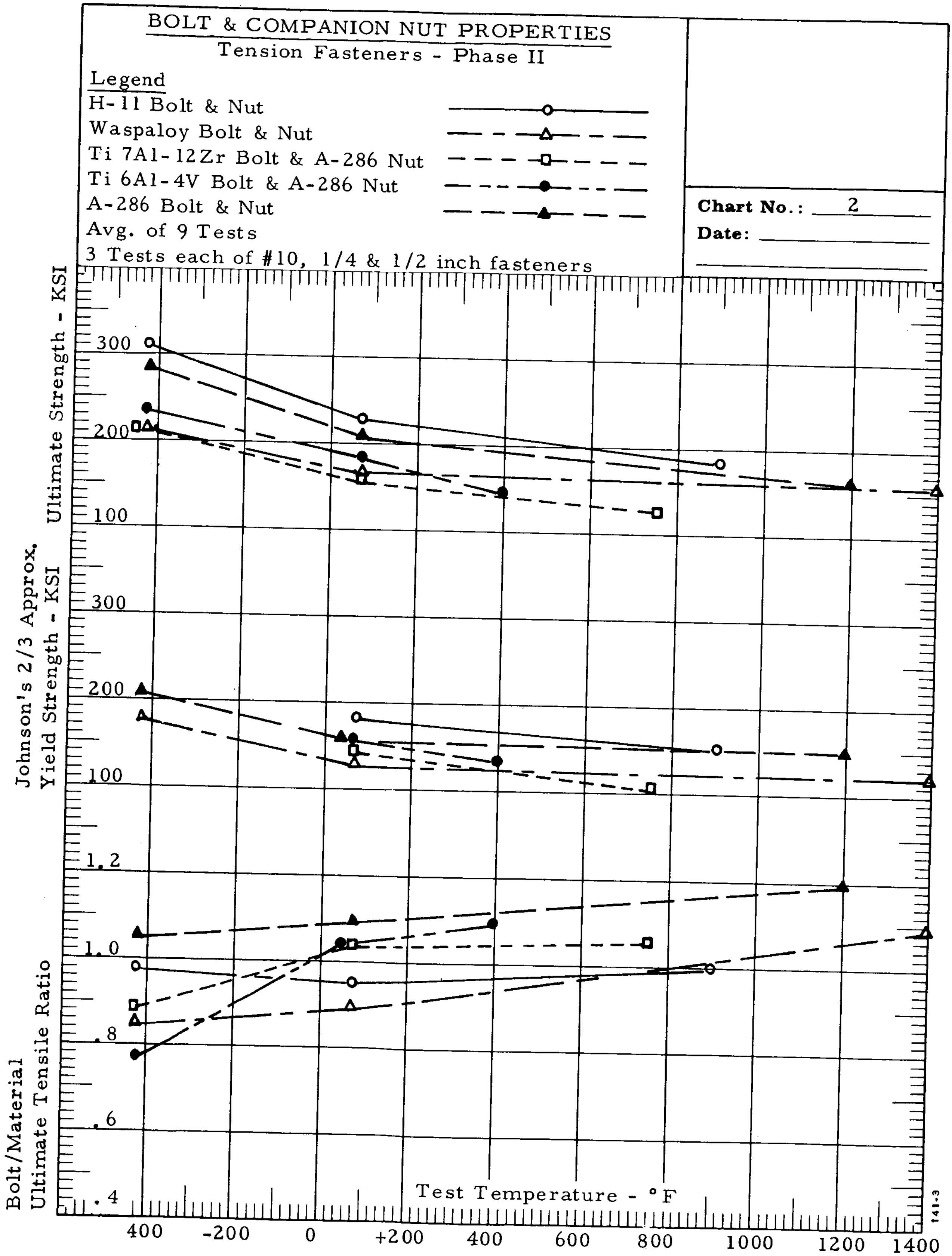
The results indicate that fasteners fabricated from corrosion resistant iron base alloys, nickel base alloys, and aluminum base alloys show definite suitability for space vehicle application from -423°F to their respective maximum utilization temperatures. Iron base and titanium base alloys have limited fastener application at cryogenic temperatures. Fastener diameter has a significant detrimental effect on cryogenic properties. The mechanical properties of fasteners and locking characteristics of nuts are not affected by thermal cycling at both extremes or by stress relaxation at elevated temperatures. Corrosion resistance of fasteners and structural materials is greatly enhanced by a coating of zinc chromate primer. The best criterion for determining a fastener's suitability for cryogenic application is testing the fastener. Finally, the determination of susceptibility of material to stress corrosion should be conducted under conditions that closely approximate actual usage. Charts 1 thru 7 summarize the results of tests on the twenty one fastener combination classes.

Five alloys of iron, nickel, and titanium base were evaluated in Phase IV. The alloys were selected by the NASA contracting officer's technical representative and consisted of Ti-1Al-8V-5Fe, 18 per cent nickel maraging steel (Vasco Max 300), U-212, Inconel 718, and 25 per cent cold reduced Waspaloy. The alloys were selected from the results of the survey on the basis of potential for high strength fastener applications and expectant future usage.

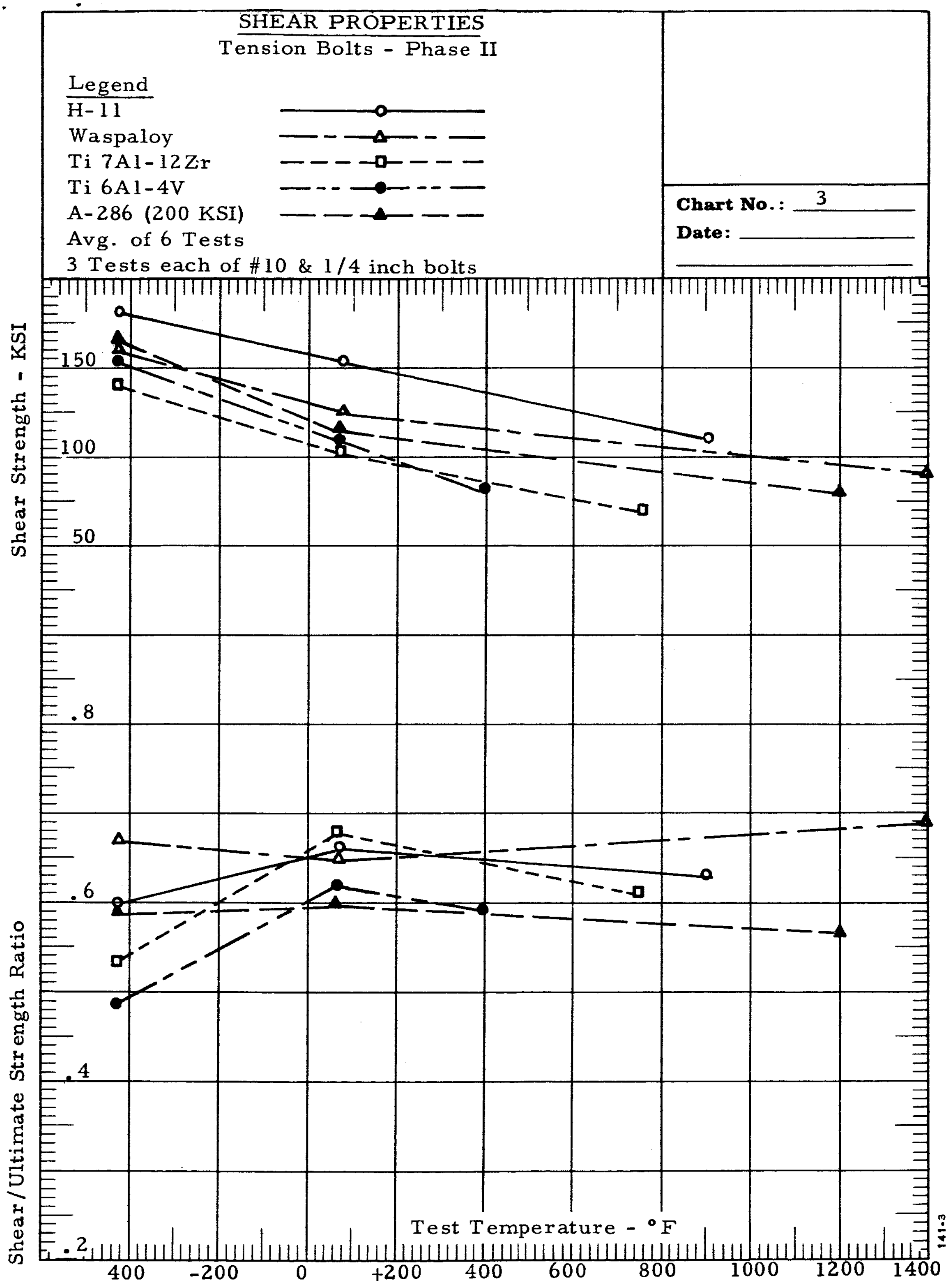
The results indicate that U-212, Inconel 718, and 25 per cent cold reduced Waspaloy show definite promise for space vehicle fastener applications from -423°F to their maximum utilization temperatures. The 18 per cent nickel maraging steel could be used for limited tension applications at -423°F. Ti 185 would not be suitable for space vehicle cryogenic applications because it is brittle and notch sensitive at cryogenic temperatures. Further work in the areas of developing a heading and heat treat process for cold reduced Waspaloy is required before this material can be utilized as a complete fastener. The summarization of the data on these five lots of material are shown in Charts 8 thru 11.

Work is continuing to determine the unique tests required to characterize fasteners specifically for space vehicle applications. Tensile and double shear tests at -423°F and at room temperature after thermal cycling at -423°F are completed. Tension-tension-fatigue, tension impact and bend tests are under way.


MATERIAL PROPERTIES
Tension Bolts - Phase II
Legend
H-11
Waspaloy
Ti 7-12
Ti 6-4
A-286
Avg. of 9 Tests
3 Tests each of #10, 1/4 & 1/2 inch bolts
Chart No.: 1
Date:
Ultimate Strength KSI
300
200
100
0.2% Offset Yield Strength - KSI
300
200
100
Gage Length
#10 & 1/4 (.113 Spec.) .5 inches
1/2 (.351 Spec.) 1.4 inches
Elongation - %
20
10
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3



BOLT & COMPANION NUT PROPERTIES
Tension Fasteners - Phase II
Legend
H-11 Bolt & Nut
Waspaloy Bolt & Nut
Ti 7Al-12Zr Bolt & A-286 Nut
Ti 6Al-4V Bolt & A-286 Nut
A-286 Bolt & Nut
Avg. of 9 Tests
3 Tests each of #10, 1/4 & 1/2 inch fasteners
Chart No.: 2
Date:
Ultimate Strength - KSI
300
200
100
Johnson's 2/3 Approx.
Yield Strength - KSI
300
200
100
Bolt/Material
Ultimate Tensile Ratio
1.2
1.0
.8
.6
.4
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3

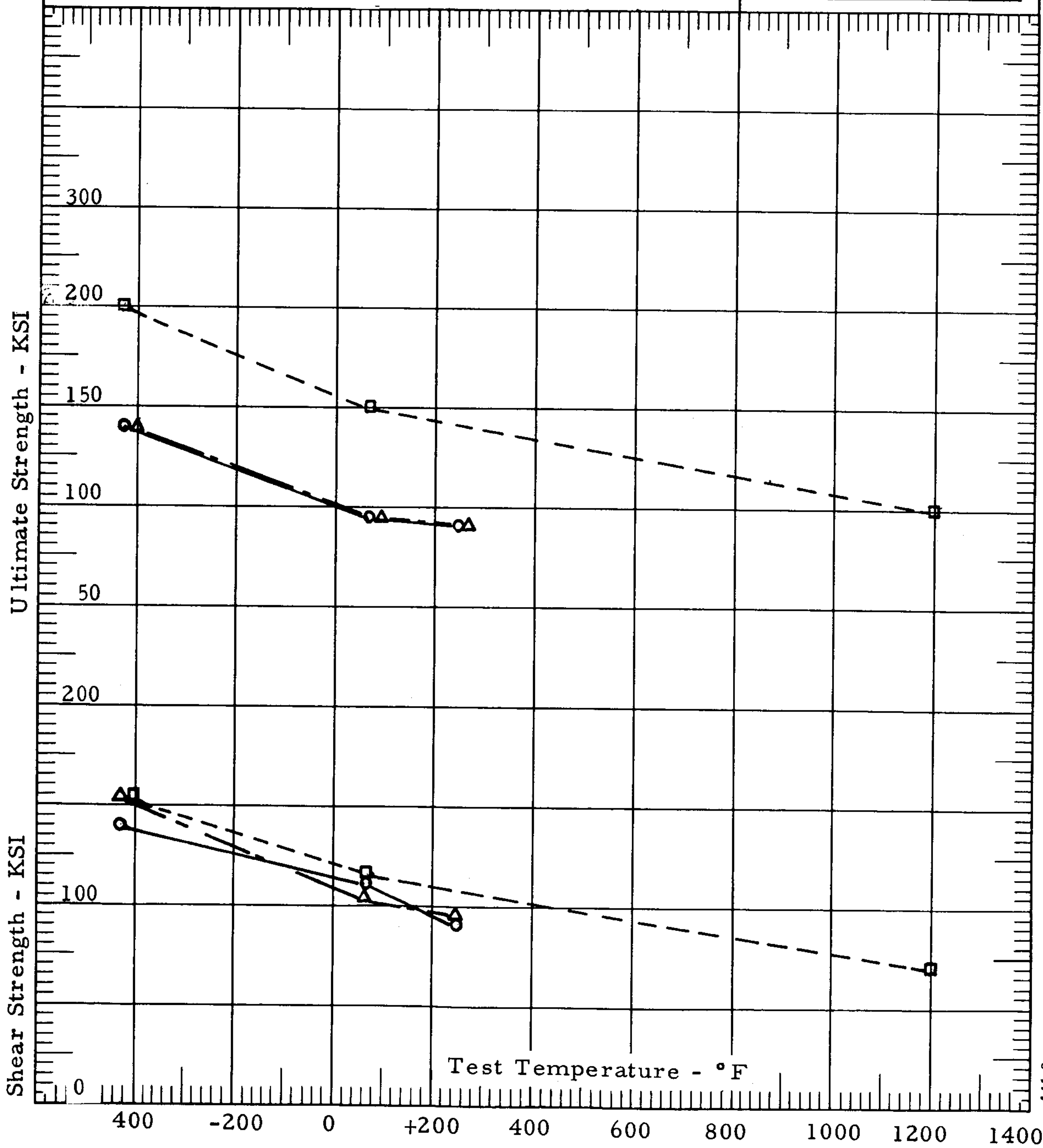

SHEAR PROPERTIES
Tension Bolts - Phase II
Legend
H-11
Waspaloy
Ti 7Al-12Zr
Ti 6Al-4V
A-286 (200 KSI)
Avg. of 6 Tests
3 Tests each of #10 & 1/4 inch bolts
Chart No.: 3
Date:
Shear Strength - KSI
150
100
50
.8
.6
.4
.2
Shear/Ultimate Strength Ratio
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3

MECHANICAL PROPERTIES

Point Drive Bolts & Twist Off Nuts

Legend
Ti 6Al-4V & 2024 Al Nut
AISI 8740 & 2024 Al Nut
A-286 & A-286 Nut
Avg. of 9 Tests for Ti 6-4 & 8740
3 Tests each of #10, 1/4 & 3/8 inch fasteners
Avg. of 6 Tests for A-286

Chart No.: 4
Date:



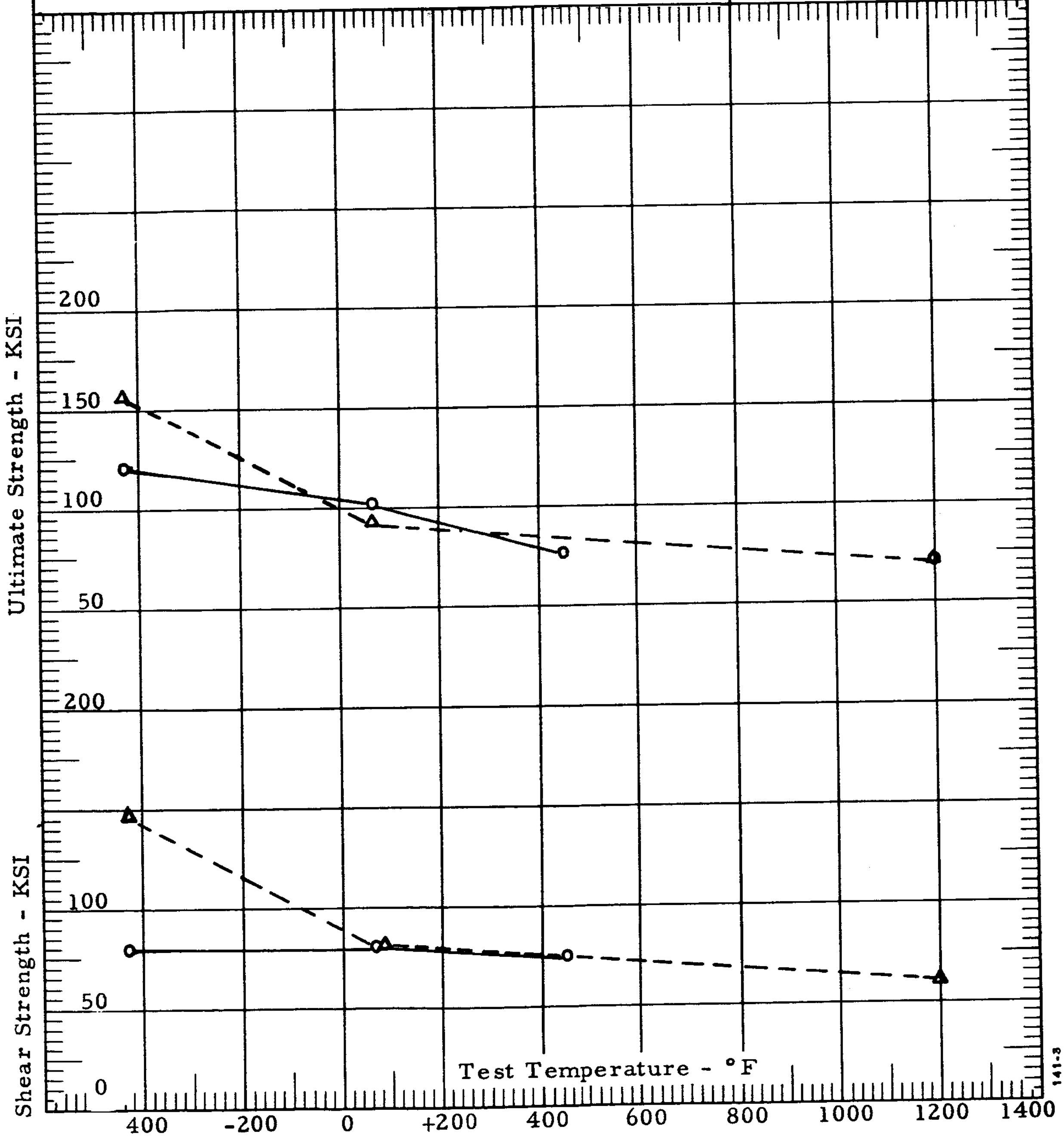
MECHANICAL PROPERTIES

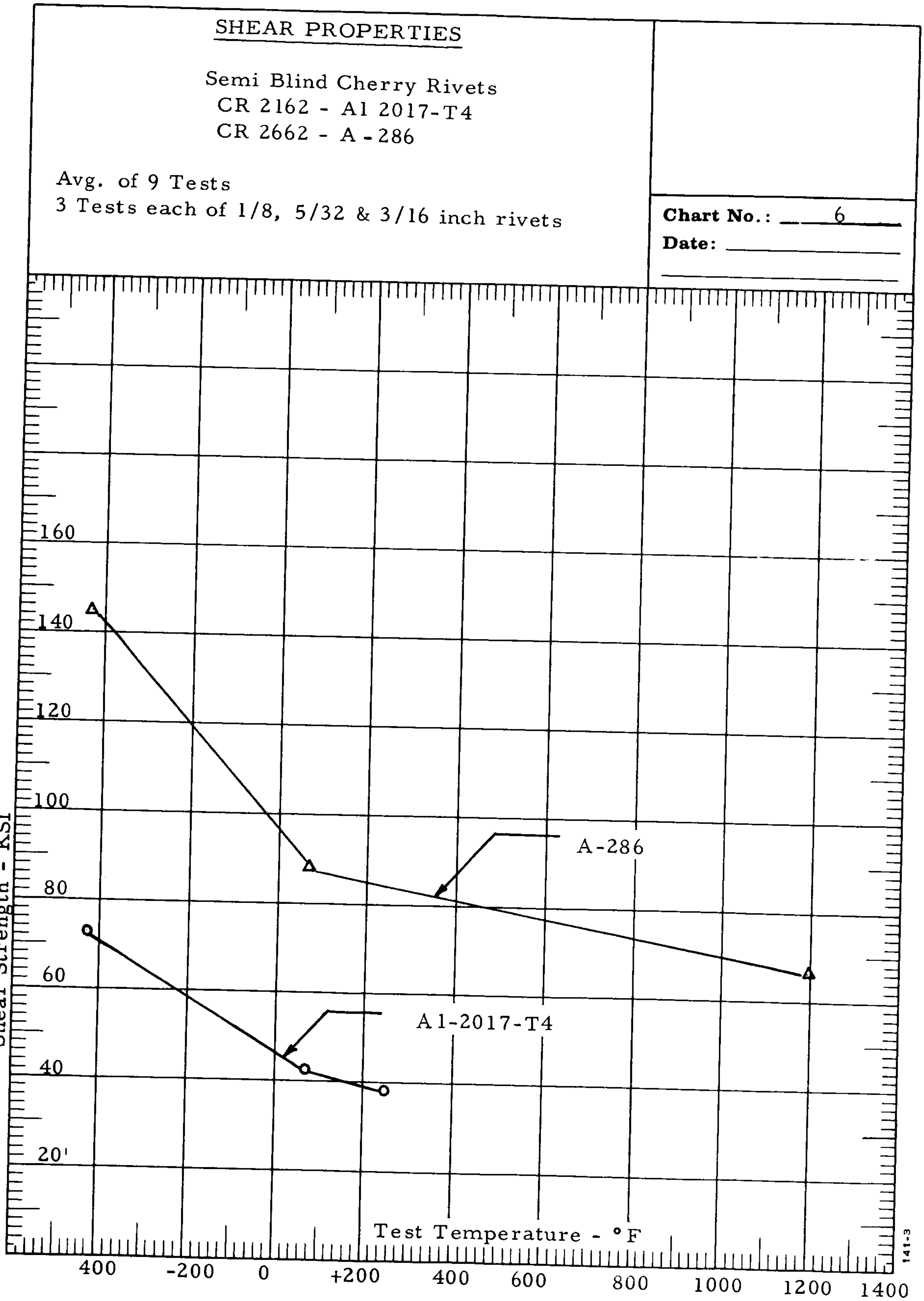
Jo Bolts

Legend
#10-32 AISI 4130
#10-32 A-286

Avg. of 3 Tests

Chart No.: 5
Date:





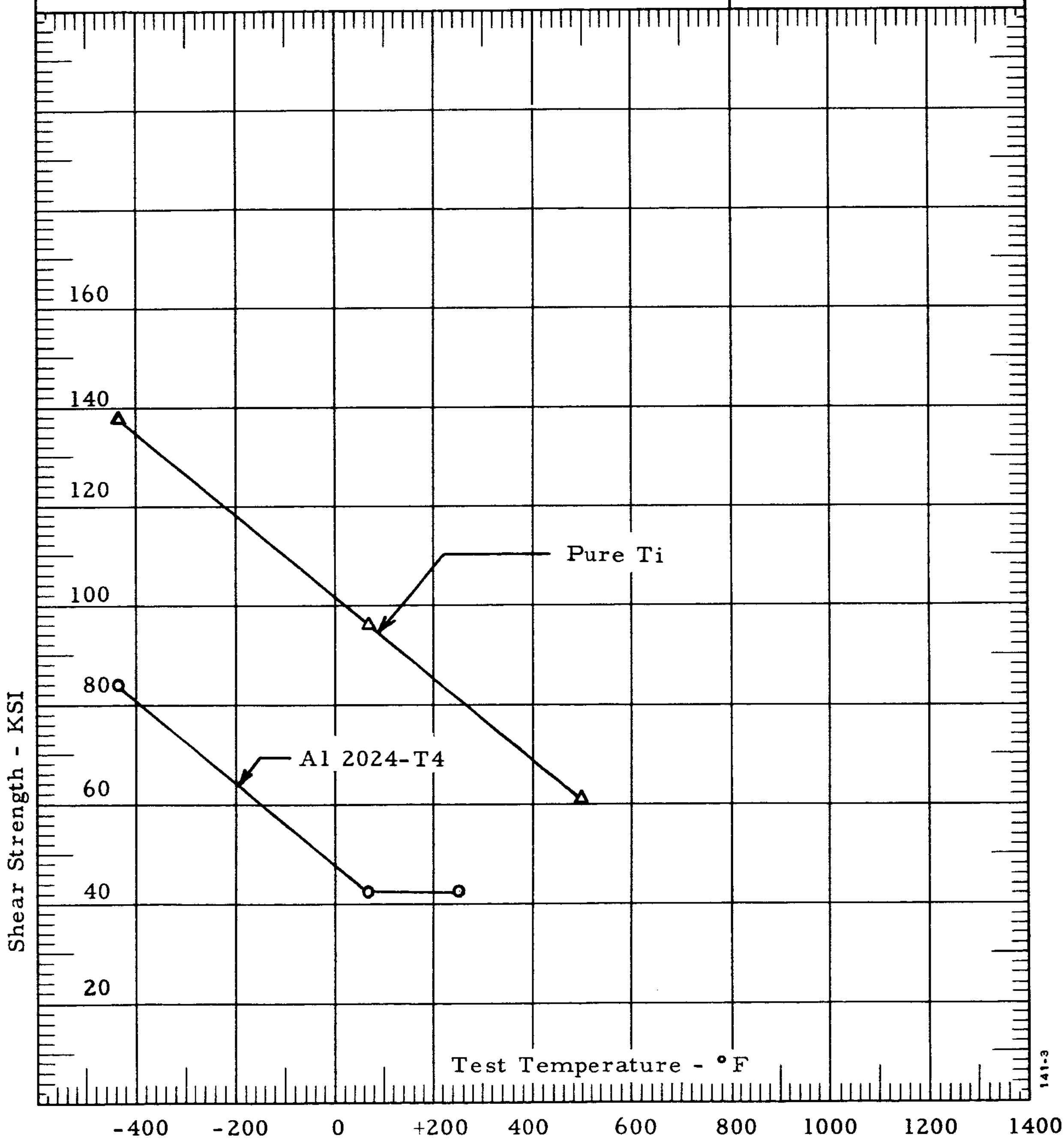
SHEAR PROPERTIES
Semi Blind Cherry Rivets
CR 2162 - Al 2017-T4
CR 2662 - A-286
Avg. of 9 Tests
3 Tests each of 1/8, 5/32 & 3/16 inch rivets
Chart No.: 6
Date:
160
140
120
100
80
60
40
20
Shear Strength - KSI
A-286
Al-2017-T4
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3

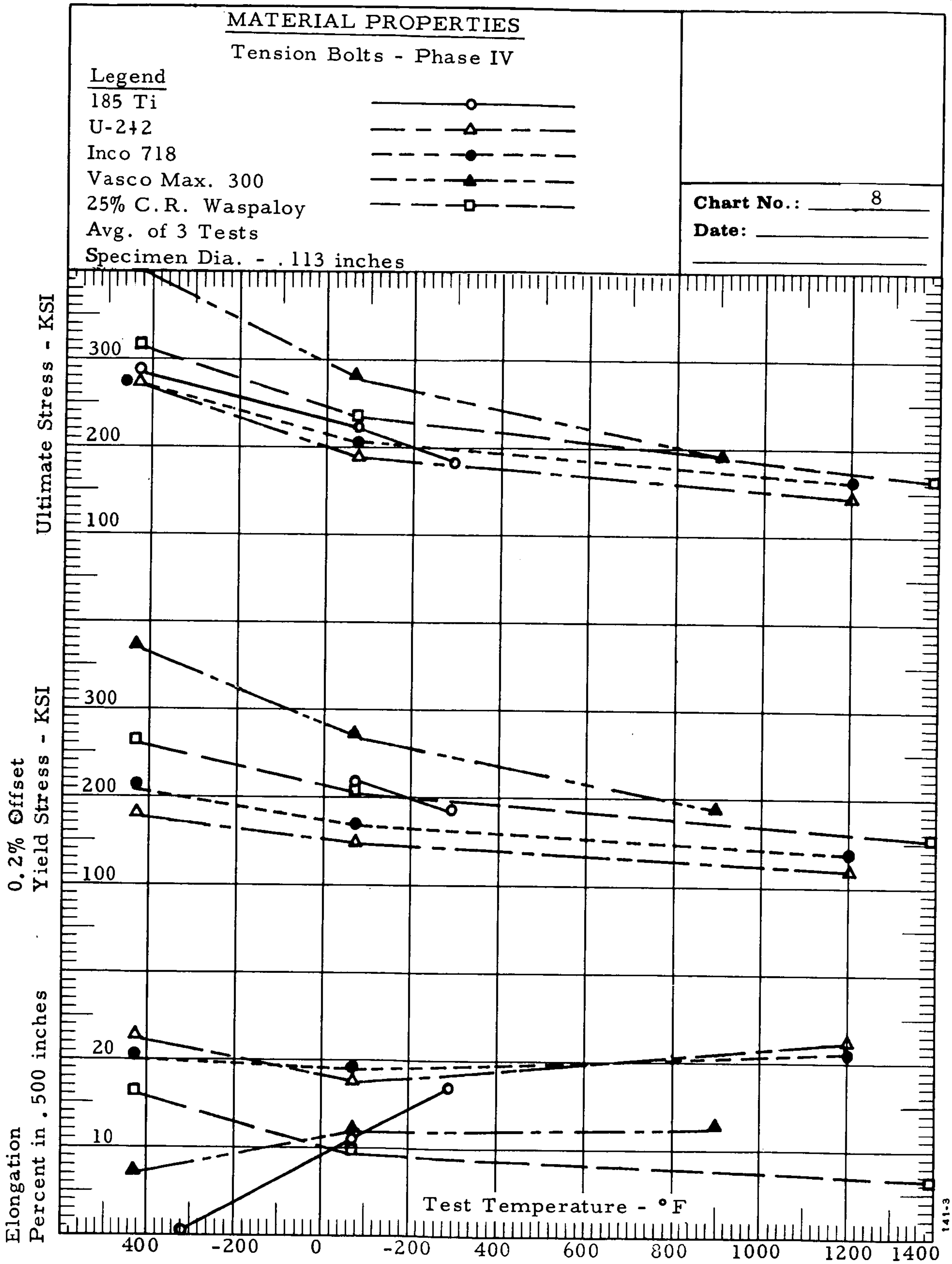
SHEAR PROPERTIES

Solid Rivets
MS 20426 - Pure Titanium 1/8 & 3/16
MS 20426 - A12024 - T4 1/8 & 3/16

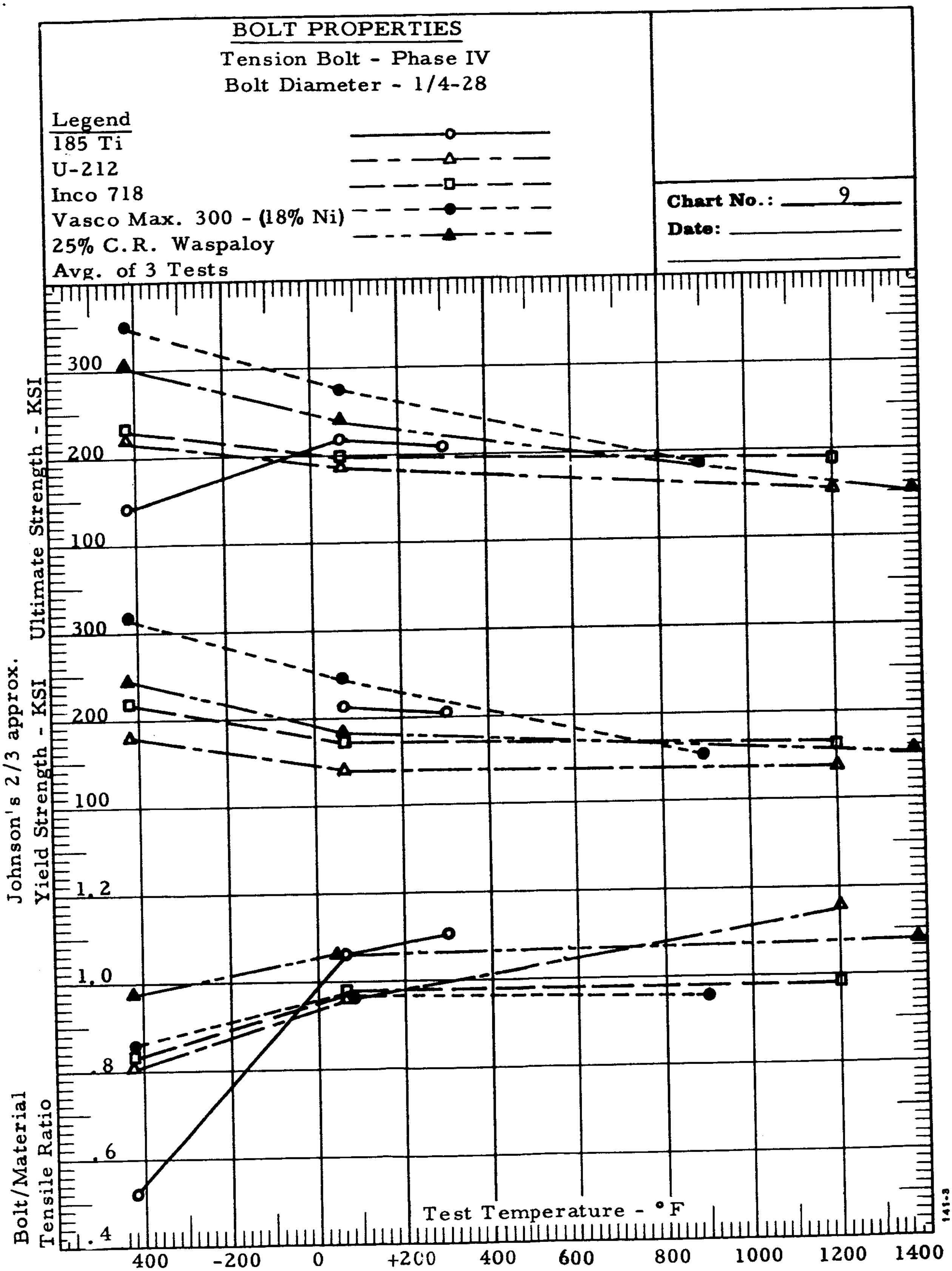
Avg. of 6 Tests

Chart No.: 7
Date:

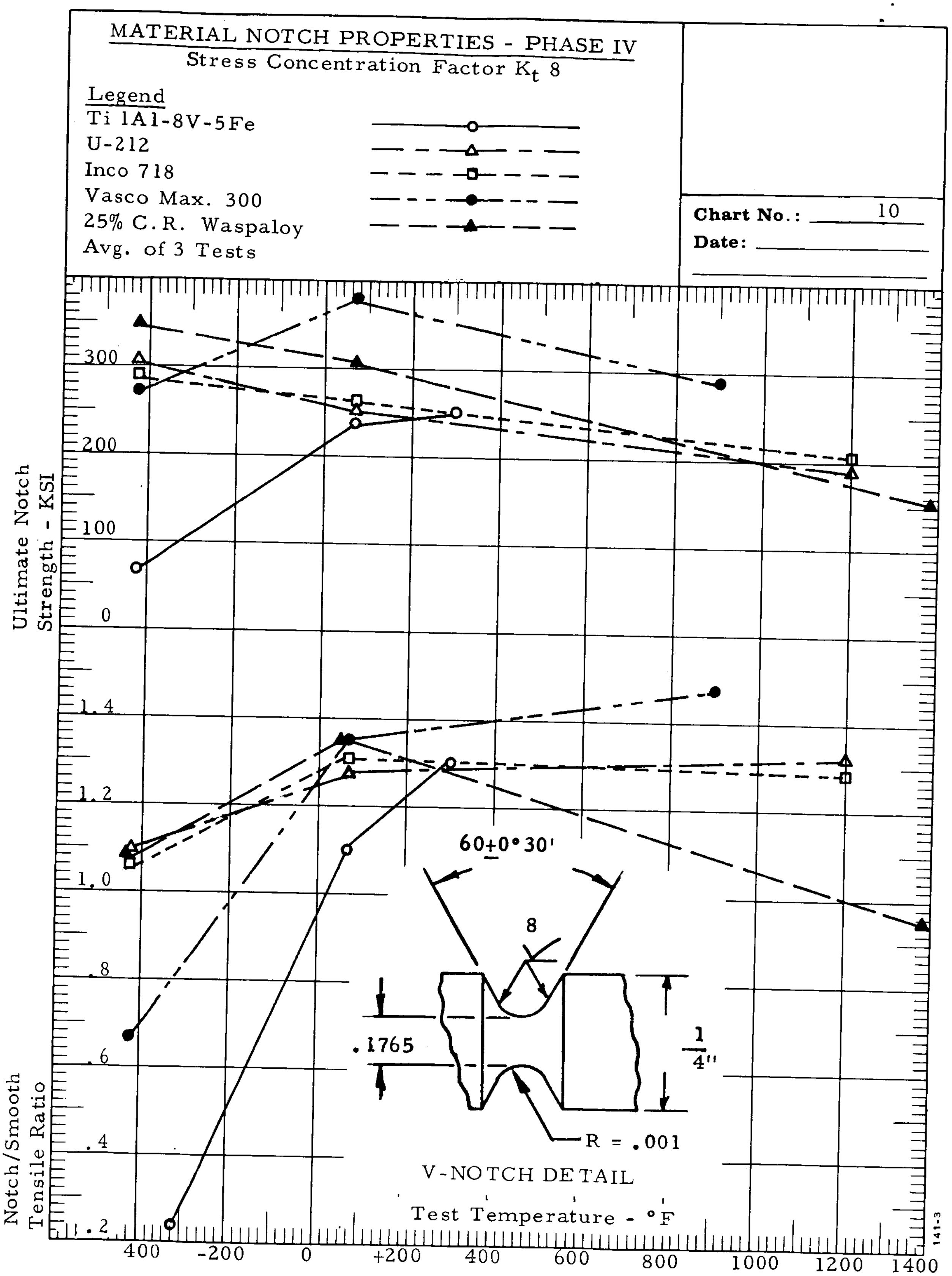


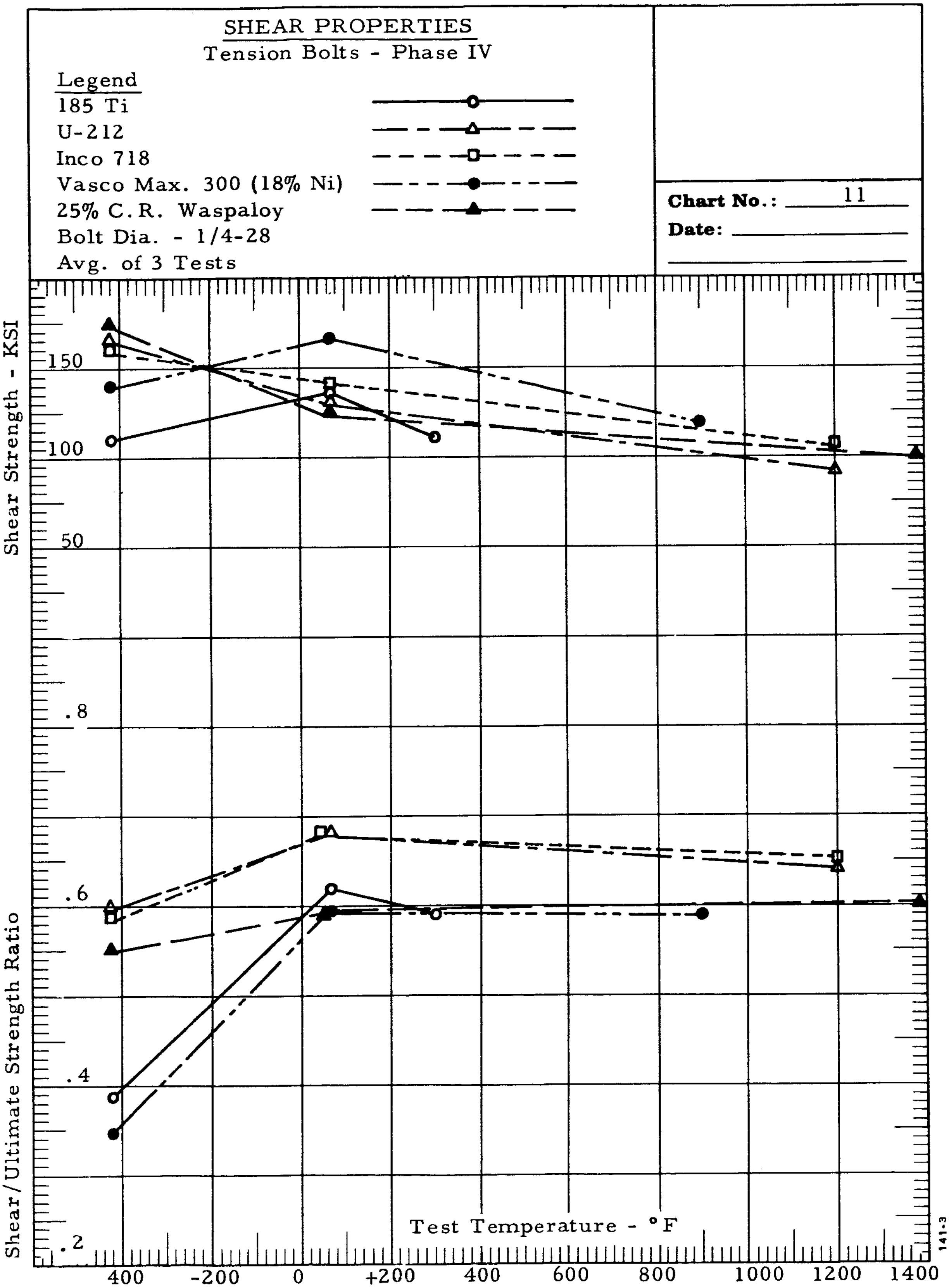


MATERIAL PROPERTIES
Tension Bolts - Phase IV
Legend
185 Ti
U-212
Inco 718
Vasco Max. 300
25% C.R. Waspaloy
Avg. of 3 Tests
Specimen Dia. - .113 inches
Chart No.: 8
Date:
Ultimate Stress - KSI
300
200
100
0.2% Offset
Yield Stress - KSI
300
200
100
Elongation
Percent in .500 inches
20
10
Test Temperature - °F
400
-200
0
-200
400
600
800
1000
1200
1400
141-3



BOLT PROPERTIES
Tension Bolt - Phase IV
Bolt Diameter - 1/4-28
Legend
185 Ti
U-212
Inco 718
Vasco Max. 300 - (18% Ni)
25% C.R. Waspaloy
Avg. of 3 Tests
Chart No.: 9
Date:
Ultimate Strength - KSI
Johnson's 2/3 approx.
Yield Strength - KSI
Bolt/Material
Tensile Ratio
300
200
100
300
200
100
1.2
1.0
.8
.6
.4
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400


MATERIAL NOTCH PROPERTIES - PHASE IV
Stress Concentration Factor K_t 8
Legend
Ti 1Al-8V-5Fe
U-212
Inco 718
Vasco Max. 300
25% C.R. Waspaloy
Avg. of 3 Tests
Chart No.: 10
Date:
Ultimate Notch Strength - KSI
300
200
100
0
Notch/Smooth Tensile Ratio
1.4
1.2
1.0
.8
.6
.4
.2
60±0°30'
8
.1765
1/4"
R = .001
V-NOTCH DETAIL
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3


SHEAR PROPERTIES
Tension Bolts - Phase IV
Legend
185 Ti
U-212
Inco 718
Vasco Max. 300 (18% Ni)
25% C.R. Waspaloy
Bolt Dia. - 1/4-28
Avg. of 3 Tests
Chart No.: 11
Date:
Shear Strength - KSI
150
100
50
.8
.6
.4
.2
Shear/Ultimate Strength Ratio
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3

SECTION II

PHASE I - SURVEY

A survey was conducted to ascertain present and future requirements for fastener utilization in the space vehicle industry and to determine which fasteners and which materials should be evaluated in the program.

The primary source of information was the aerospace industry comprising the NASA contractors and NASA installations shown in Table 1. In addition, the fastener manufacturers shown in Table 2 were contacted for information. The information sought fell into five major categories:

1. Materials, Fasteners, and Structures

2. Fastener Configurations

3. Application and Design Criteria

4. Testing and Test Methods

5. Fastener Information and Specifications.

A. FASTENER MATERIALS - PRESENT USAGE

The present usage of fastener material falls into the categories of aluminum, alloy steel, stainless steel, nickel base alloys, titanium, and refractory alloys. Table 3 lists the present usage of fastener materials.

1. Aluminum

Aluminum (particularly the 2000 series aluminum) is used mainly in the fabrication of rivets with very few applications for bolts. The universal and the semi-blind rivet with swaged collars are used extensively in skins and other sheet areas. Good ductility and compatibility with structures are the chief assets of aluminum.

2. Alloy Steel

The use of alloy steel is wide and varied; except for use in the semi-blind point drive bolts, quantities of any specific material are small. Habit and reluctance to change seem to prescribe the large use of 1100 and 4000 series materials at moderate stress levels. However, loading factors are on the increase and resultant higher strength requirements are forcing greater consideration of higher strength fasteners. Generally though, the regular alloy steels are not included in these considerations.

TABLE I

NASA CONTRACTORS AND INSTALLATIONS

1. Grumman Aircraft Engineering Corp., Bethpage, New York
2. Republic Aviation Corp., Farmingdale, New York
3. Martin-Marietta Corp., Baltimore 3, Md.
4. Thiokol Chemical Corp., Elkton, Md.
5. General Electric Co., Phila., Pa.
6. Langley Research Center, Hampton, Va.
7. Goddard Space Flight Center, Greenbelt, Md.
8. Boeing Co., Seattle, Wash.
9. North American Aviation, Canoga Park, Calif.
10. North American Aviation, Downey, Calif.
11. Lockheed Missile & Space Co., Sunnyvale, Calif.
12. United Technology Corp., Sunnyvale, Calif.
13. Cal Tech Jet Propulsion Lab, Pasadena, Calif.
14. Space Technology Labs, Redondo Beach, Calif.
15. Martin Marietta Corp., Denver, Colo.
16. Lewis Research Center, Cleveland, Ohio
17. McDonnell Aircraft Corp., St. Louis, Mo.
18. Pratt & Whitney Aircraft, West Palm Beach, Fla.
19. Boeing Co., New Orleans, La.
20. Chrysler Corp., New Orleans, La.
21. Marshall Space Flight Center, Huntsville, Ala.
22. General Dynamics, Astronautics, San Diego, Calif.

TABLE 2

FASTENER MANUFACTURERS SOLICITED

1.	Briles Manufacturing Co.	-	El Segundo, California
2.	Camcar Screw & Manufacturing Co.	-	Rockford, Illinois
3.	Elastic Stop Nut Corp. of America	-	Union, N J.
4.	H. M. Harper Co.	-	Morton Grove, Illinois
5.	Huck Manufacturing Co.	-	Detroit, Mich.
6.	Hi Shear Rivet Tool Co.	-	Torrance, Calif.
7.	Kaynar Manufacturing Co.	-	Fullerton, Calif.
8.	Lamson & Sessions Co.	-	Cleveland, Ohio
9.	Screw Corporation	-	City of Industry, Calif.
10.	Townsend Company		
	a. Boots Aircraft Nut Div.	-	Norwalk, Conn.
	b. Cherry Rivet Division	-	Santa Ana, Calif.
11.	Standard Pressed Steel Co.	-	Jenkintown, Pa.
12.	Valley Bolt Corporation	-	N. Hollywood, Calif.
13.	Voi-Shan Manufacturing Co.	-	Culver City, Calif.

TABLE 3

FASTENER MATERIALS - PRESENT USAGE

Company	Aluminum	Alloy Steel	Stainless Steel	Nickel Base	Titanium	Other
Chrysler-New Orleans	2024, 5056	1100 series, 4000 series 8000 series	A-286 300 series	Monel		
Martin-Denver	2024	H-11(small amount)	A-286, 15-7 Mo	Inconel X Monel		
NAA-Downey			A-286, 300 series			
NAA-Canoga Park		4000 series, 8000 series	A-286 (140, 200 ksi)	K Monel(-350°F) Inconel X (160 ksi - Room) Rene 41 (180 ksi 1400°F)	6-4	
LMSC	5056, 2117, 7075	almost none	A-286	M-252, Inconel X Rene 41	6-4, 4-4	
United Tech	7075, 6061	H-11. D6 AC	A-286			Temp. Requirements of -70°F to +500°F
Boeing-Seattle	2017, 2117, 5056 2024 rivets 7075 bolts	4037, 4130, 8630 8740, 4340, (160/180) H-11 (220/260)	A-286, 303, 321	Monel (rivets) Inconel X, M-252 Rene 41, Waspaloy	6-4, 4-4	TZM, D-36
Thiokol-Elkton		H-11, 4130, 4140, 4340	410, 17-4PH, 304			Very little high temperature
Martin Baltimore	2024, 2017, rivets 5056, 1100	4130, 1025, 4340 H-11	A-286, 300 series 431, 17-4 PH	Inconel	6-4, 4-4 (small amount)	
McDonnell	7075, 2024	H-11, 4300 series	A-286, 300 series	Monel (rivets) AF1753, Inconel	6-4	L605 Co Base Cb, TZM, D-14
Grumman	2024, 2117, 5056	4130, 4340, 4037	A-286, 437 300 series			
Republic	2017, 2024	4130, 4340, 8000 series	300 series			
Lewis Research Center	2024 (rivets)	1100 series, 4000series	300 series	None	None	Mo
Marshall Space Flight Center	2024, 5056, 7075	1100 series, 4000series 6000 series, 8000series	A-286, 300 series			
Jet Propulsion Lab	2024 (rivets)		A-286 (160 ksi) 300 series		6-4 (160 ksi)	
PWA-West Palm Beach			A-286	Waspaloy, InconelX		
Boeing New Orleans	2024, 5056, 7075	4140, 4340, 6150 8735, 8740, 4037	A-286			
Space Tech Labs	2024, 6061, 2014 2017	Undesignated alloys (small amount)	A-286, 300 series 17-4 PH		6-4	Si-Bronze Al-Bronze Be-Cu
G. E. Phila	2024 (nuts)	1100, 4000, 8000 series Maraging	A-286, 431 300 series	None	None	
General Dynamics/ Astronautics		H-11	A-286 (140 ksi)		6-4	
NASA, Langley			316 S/S			Super Alloys to 1600°F

3. Stainless Steel

For cryogenic and moderate to high temperature applications, corrosion environments, critical impact and sonic vibrational areas, the stainless steels of the 300 series, 17-4 PH, 15-7 Mo, and A-286 are used. The A-286 alloy commands the most usage.

4. Nickel Base Alloys

With the exception of Waspaloy and Monel which have exhibited good cryogenic properties, most of the nickel base alloys are being used for high temperature requirements up to approximately 1800°F. The applications are primarily for engines and nearby structures and on re-entry vehicles on which exposures are for a relatively short duration. Stress rupture and stress relaxation properties are the governing factors in the selection of nickel base alloys.

5. Titanium Alloys

The use of titanium alloys is on the increase in space vehicle applications. The material offers the advantage of good strength-to-density ratio, corrosion resistance, and low magnetic properties. At present, the primary interest is the Ti-6Al-4V alloy thermal treated to 160 ksi. However, increasing interest has been expressed in the low interstitial alpha-beta alloys and the super alpha alloys for cryogenic and elevated temperature applications.

6. Refractory Alloys

The refractory alloys are primarily used in re-entry vehicles. Except for molybdenum and columbium alloys for high temperature applications above 2000°F, there are very few other materials being utilized.

B. FASTENER MATERIALS - EXPECTED FUTURE USAGE

At present, there does not appear to be a great demand for new and better fastener materials. Most people are thinking in terms of presently available materials with which they have had some experience; while others expressed interest in upgraded materials that are similar to present types. Those materials which are being considered for future use are listed in Table 4.

TABLE 4

FASTENER MATERIALS - EXPECTED FUTURE USAGE

	Refractory Alloys	Nickel Base	Stainless Steel	Titanium	Alloy Steel	Other+Remarks
Chrysler, New Orleans		1600° Usage	A-286 HS	6-4		
Martin-Denver	Mo, Cb - 2500°F re-entry	Waspaloy, M252 (3000-4000° for 4-5 sec. duration)		Undesignated-NAS 1273 & 1153 around engine compartment & fluid lines Titan III		
NAA-Downey	Mo, Cb (better than present)					Some, but not much concern for cryogenic materials
NAA-Canoga Park		Waspaloy, Inconel 718 (270 ksi)				Gas generators have highest temp. (1400°F)
LMSC		AM 367		Undesignated	18% Ni Mar-aging	Lockalloy (60 Be 40 Al) (composite) Be
United Technology		Inconel (220-260 ksi)			Better toughness than H-1 1 and D6 AC 9% Ni Mar-aging	
Boeing-Seattle	Tungsten, pure Mo, Ta, better Cb, better Mo					-452° to +4500° 325 ksi
Thiokol Elkton	Tungsten			Undesignated	Mar-aging	Be
Martin Baltimore	Tantalum, Zr, W Mo, Cb	Waspaloy(cryogenic)	A-286 (cryogenic) 300 series			6061, 5456 (cryogenic)
McDonnell	Ta, W (3500°-5000°) new Mo and Cb alloys (B-66)	Waspaloy, U-700 undesignated Astraloy TD Ni (1800°-2400°)	U-212 undesignated aust. stainless steel for cryogenic	Low intersitial Ti 8-8-1 Ti (700°)		Be, Need materials with cryogenic&high temp, props, in one.
Grumman	Undesignated			6-4, 4-4 undesignated		Be
Republic	Cb, B66, Ta, Cb 752	Rene 41, Hastelloy X T.D. Ni		6-4, Hi Strength Ti		Be, Composite heat barrier fasteners
Lewis Research Center	Undesignated-4000°					Be
Marshall Space Flight Center	Tantalum, Molybdenum columbium, tungsten		U-212			Be
Jet Propulsion Lab						
PWA-West Palm Beach		Inconel 718				
Boeing-New Orleans		1500° Usage				
Space Tech. Lab	Tungsten	K Monel, Inconel 718				
G. E. -Phila.						
NASA Langley						Existing fasteners are adequate
General Dynamics		Inco 718, Rene 41, Rene 62	A-286 (200 ksi)	6-4 ELI		

1. Alloy Steels

The only alloy steel given any consideration for future fastener usage was the 18 per cent nickel maraging steel. The number of people considering this alloy were very few. In general, alloy steels are not being considered for future applications.

2. Stainless Steels

Outside of U-212, high strength A-286 and several austenitic stainless steels, no other materials were suggested in this category by the people contacted as being significantly worthy of development.

3. Nickel Base Alloys

Many nickel base alloys are being considered for future application. These alloys include Waspaloy, Rene 41, Hastelloy X, Inconel 718, and M-252. Applications for these materials encompass a wide range. First, there is the cryogenic area with a need for high strength, above 200 ksi, with good toughness and impact strength down to LH_2 temperatures.

Corrosion resistance to fuels, oxidizers, high humidity, and other atmospheres is an important characteristic of the nickel base alloys.

4. Titanium Alloys

Titanium alloys have been accorded increased consideration for future boosters, but some companies are not thinking beyond presently available materials such as 6-4 and 4-4 alloys. However, the need is recognized for reliable titanium alloy fasteners with higher usable strength and higher temperature performance.

5. Refractory Alloys

Future use of refractory alloys points to limited application for molybdenum alloys, expanded application for columbium alloys, and the additional use of tantalum base alloys. In each case, the utilization of a specific alloy or alloy series is limited more by the state of the coating art than by structural considerations.

C. FASTENER CONFIGURATIONS

Where possible, most companies are using standard fasteners as called out by AN, NAS, and MS drawings. Where standards do not exist in the area of higher strength and higher quality fasteners, the companies are creating their own standards, or in some cases using the standards of fastener manufacturers. Table 5 lists the present types of fasteners being used.

D. APPLICATIONS AND DESIGN CRITERIA

Information was obtained about application conditions and factors which influence the selection of fasteners and the materials from which they are fabricated. Such items were examined as types of loading experienced by fasteners, environments which may affect fastener performance, torque versus induced load concepts, preferred platings and lubricants, compatibility of fasteners with structural materials and installation and installation problems.

1. Types of Loading

The majority of users indicated that the various fasteners in their structures underwent combinations of all possible types of loading. These consist of tension, shear, combination of tension and shear, torsion shear, bending, static, dynamics, impact, vibration, and "G" loading. But very few of the types of loads are significant at any one time or place.

Shear is most prominent because design practices favor it. Structures, skins, and attachments are designed in shear. Tension usually with bending was next in area of thrust structures, engine mounts, fins, bulkheads, pump flanges and injector domes. In tension application most loading is static. Dynamic and impact loads were at a minimum.

2. Environments

The two most significant environmental conditions to be contended with today are all types of corrosive influences and cryogenic influences.

The indicated problem areas of corrosion are:

a. Room and cryogenic corrosion because of fuels and oxidizers.

b. High humidity and salt atmosphere corrosion.

c. High temperature corrosion.

d. Stress corrosion

e. Galvanic corrosion.

TABLE 5

PRESENT FASTENER USAGE

Company	AN	NAS	MS	Others + Remarks
Chrysler	3-20 362 173 366 363 123508 361	1297 3003 687 1023 624-44 1298 563 696 686 1299 679 1032 680 698 509 1025 697 1033 671 1068 624 1003 1021 1024 1031	20073 35305 21046 9033 20074 35306 20501 20365 20033 20500 20426 20364 35298 21042 20470 35692 35304 21044 20435 35691 35649 21045 35650 35690	Huck (largest quan.) Threaded 40% Hi Lok Rivets 20% Threaded -#2-1 1/2 Huck 40% Non-threaded - 1/8-3/8 Hi Lok Total fasteners/veh ≈ 10,000
Martin-Denver	3-20 Steel 3-20 A-286	A-286 624 (increasing) 1291	A-286 20004	A-286 H-11 15-7 *Hi Lok 140 EWB(few) EWB (280) EWSN26 and (220-260) EWSB FN22 160 to Inconel X 42FW 200 ksi Rivets *Expected big quan.
NAA-Downey		A-286 1003 501 1100 686 (140 ksi) 1630 1620 1151	A-286 21043 (140 ksi)	A-286 (NA) (Phillips, flush, & pan) EWB (8879 th'ds.) (heads up to 140 ksi) EWSB EWN (over 140 ksi) (Torq-set drive over 140 ksi) Most parts other than standard items are under NAA drawings
NAA-Canoga Park		A-286 Ti 1000 623 - 625 (R D dwg longer th'd)	A-286 20004 21277 (full P. D.) 21250 (tank area)	RD dwgs. 111-1000 series (hex) 111-3000 series (int. hex) 140 ksi 111-4000 series (12pt.) 200 ksi (Use of Ti expected to increase.) Undesignated EWB&EWSB (Inconel) (E-25 criteria) (Rene 41)
LMSC			20426 Rivets	Ti (6-4) Al Huck Huck Hi Lok
Boeing-Seattle	3-20 774 500-26 775 310 6289 315 924 316 320	1103-20 623 1303-20 1189 583-90 1191 1503-10 679-90 600-06 514	9441-59 20004-24 20364 9433-37 20007 3&74 20365 9399-402 16995-98 35649 9449-50 35297&98 35650 9360 21262#295 25082 9107-08 24615-630 21042 20500 21043	BAC 21 AS-CE N10ED-DN
Boeing-New Orleans		1103	21250 20004	A-286 Hi Lok Hex hd. (160-180) A-286 12pt. tension(180)few Steel 12pt. nuts (180) Titanium (increasing)
Thiokol-Elkton	3-20 363	1398 (M4-2) 686 687 1144 1102	20427 (M3 & M4 -4-6) 24677 21250	Mostly tension fasteners LWB 22 EWB type Stainless Steel Special SHCS Stainless Steel
Martin-Baltimore	3-20	220 - 227 464 679 334	20004	EWB 26 Martin 26D Martin 8 Martin 9 Martin 15
G. E. - Phila.		(Almost all miniature plate nuts) 1291 1102 A-286 333 (600/veh)	431 Stainless Steel 20004 (600/veh)	(100% Phillips Drive) where applicable Swage Nuts Cherry Rivets Hi Lok Bolts Jo Bolts (6000/veh) Milson (100/veh) Majority of applic. are shear sizes Sizes are 1/4 and below.
Space Tech. Labs	300 series 500 series	Ti 653 (NAS 621) 1100 Undesignated	Undesignated	STL miniature Size range below 0-80 to #10 Huck blind rivets Jo bolts (A-286 few)
Jet Propulsion Lab.			2004 (A-286 and 6-4) (JPL dwg.) (160 ksi) 21043	Dome Rivets Size range - #2 to 1/4 -200° temp. limit
Republic	3-20 C	1132 1217C 1133 C3 1151 to 1153 C7 1154		Undesignated specials of Ti, Waspaloy, and Rene
McDonnell		560H		3M 133 3M 123 Monel rivets Approx. 300 threaded fasteners per Asset vehicle.
Marshall Space Flight Center	4-16 509 DD 4-16 DD 508 42B-49B	1221 1104-16 1352 1221C 1218C 1352C 1218 1221C 1304 1586 584-90 1004 1351 564-72 1351C		Mc 624 625 626 611 612 613 614
General Dynamics/ Astronautics	3-20 509 427M	514 1102 1151 464 1003 1020 501 673 1351 1352 1100 1141	35289 20500 20601B 2004 21043 20600B 17829 20426B 20601MP 21042 20470DD	H-11 EWB-22 Current fasteners will be used in the future

Where feasible the first three problem areas have been remedied with A-286 and other stainless steels and nickel base alloys.

Cadmium plating between the A-286 and aluminum structure appears to prevent galvanic and stress corrosion in most cases. However, there are many specific problems in this field about which there is very little knowledge.

The effects of cryogenic temperatures on fastener properties are the second major environmental condition. Although considerable fastener data has been generated at -100°F and some at -320°F, very little fastener data at -423°F is available. Therefore, tensile and shear testing at -423°F is clearly indicated, with impact and fatigue testing needed as soon as possible.

Other environments that influence fastener selection are high temperatures, cycling between temperature extremes, vacuum, and radiation.

Elevated temperature problems are relatively straightforward and considerable advancements have been accomplished in this area.

Temperature cycling between temperature limits has not been investigated to any great extent but warrants definite investigation because fasteners do experience this condition both on the ground, under fuel cycling conditions, and in space. However, because there are very few applications involving cycling between cryogenic and elevated temperatures, studies should be conducted by cycling from room to -423°F to room and from room to maximum applicable temperature to room temperature. Ten cycles was a reasonable figure to start with on the basis of comments.

Vacuum and radiation properties are considered of prime importance by space vehicle builders. The vacuum environment presents problems because many platings sublimate and redeposit elsewhere, and those platings which do not sublimate do not always provide sufficient corrosion protection or prevention of galling between external and internal threaded fasteners.

Radiation was indicated as a potential fastener problem by only three groups. At this point, it seems doubtful that anyone has enough data on the problems connected with radiation and it has been classified as a future area of study.

Table 6 shows a condensed summary of the various loading conditions and environments reported by the users.

3. Tightening

Survey information on torque versus induced load applications indicate that a lack of information prevails in this area. Many users refer to HIAD values for general conditions and company or vendor generated data in the non critical areas. Table 7 gives a breakdown of preferences.

4. Platings, Coatings, and Lubricants

a. Platings and Coatings

The number of protective finishes used in various space vehicles is extensive. Table 8 illustrates this variation.

Cadmium, the largest single item, is used in two areas. One application is the conventional corrosion resistance on alloy steel bolts for use up to 450°F. Specifications for this type of plating are usually QQ-P-416a (Type II) or MIL-C-8837 (Type I). The other application is to prevent galvanic corrosion on A-286 or other stainless steel bolts and aluminum structures. Generally QQ-P-416a, Type I or II is employed.

Diffused nickel-cadmium is used as a protective finish for alloy steels for applications up to 900°F temperature. AMS 2416 specification covers this type of plating.

Silver is primarily a lubricant for high temperature applications on corrosion resistant fasteners in steel and other structures where galvanic corrosion is not a problem. It is also used because it does not sublimate. The specification is usually AMS 2410.

Gold and aluminum are thermal control platings. In addition, gold is satisfactory where sublimation in vacuum is a problem. Other coatings such as Electrofilm are really lubricants and provide minimal corrosion protection.

b. Lubricants

Molybdenum disulphide in various formulations is the most extensively used lubricant. However, it is restricted in two areas - liquid oxygen proximity and vacuum conditions. Other lubricants for the most part are rather selective in

TABLE 6

APPLICATIONS & DESIGN CRITERIA

Company	Loading Conditions	Environments	Other
Chrysler	Primarily shear a few tension areas on fins no fatigue problems	Corrosion - atms., galvanic, fuel a few high temp. areas (1000°F) cryogenic temp. (-423°F) Lox compatability important	Mil Hbdk 5 D. A. (design allowables) Hi Lok and Huck Bolts difficult to pull up in Stainless Steel
Martin-Denver	Some tension - More shear Bending, but not a problem	Temp. cycling -423°F to 2500°F Future fuel and oxidizer corrosion Unknown space environs - future	Mil Hbdk 5 + Martin Hbdk D. A. wt. generally not a consideration Going toward fewer but larger fasteners
NAA-Downey	Primarily shear-go out of way to use double shear - single shear next. Some bending engine mount & flanges. Some tension - High sonic vibration levels (170db) but structures are weak spot-fatigue loading due to vibration	Temp cycling -423°F to room Temp limits - 423°F to + 1600°F a few to + 2400°F Corrosion - oxidizer + fuel + atms.	Mil Hbdk 5 modified by company generated data for D. A. Strength/density important but not critical Going toward larger but fewer fasteners higher reliability
NAA-Canoga Park	Primarily tension - Some shear Some bending - flanges - Most loads are static, but some short duration, high amplitude dynamic loading - increasing criticality High magnitude (700), instantaneous G loads	Corrosion - atms. temp., fuel & oxidizer - Temp. limits -423°F and 1000° - Space vacuum - no major probs. Radiation no problem - Temp. coeff. of expansion important	Coeff. of expansion compatability Except higher loadings and more corrosion for future. Mil Hbdk 5 + NA design manualD. A. Safety factor of 1.5 - Strength/density ratio not critical now - becoming more important. Higher reliability increasing.
LMSC	90% shear applications Some tension - Some bending No fatigue "G" loads in tension and bending	Atms. corrosion - Temp. limits -70° to + 800° Space vacuum sublimates some coatings. Radiation not problem at present	Mil Hbdk 5 + Lockheed documents on A-286 for D. A. No yield at limit load allowed - Size limitations - #10 screws and 1/8" rivets min. in primary structure.
Boeing -New Orleans	Many shear - Few tension No fatigue now but will increase due to ultrasonic vibration	Temp. cycling -423°F to room a few applications -423°F to + 1500°F galvanic and fuel corrosion	Mil Hbdk 5 + Boeing Hbdk D. A.
Boeing - Seattle	All types of loading Shear - torsion (75%) on Dyna Soar - Some impact Some vibration	Short time stress corrosion Space vacuum for plating Temp. cycling Galvanic corrosion	Mil Hbdk 5 modified D. A. Strength/density important - Moving toward generally tighter AQLS and statistical evaluations. Problem of putting refractory bolts together
Thiokol	Tension & bending in pressure vessel bulkheads + impact, vibration and "G" loads	High humidity atms. corrosion fuel corrosion	Mil Hbdk 5 + vendor data for D. A. Strength/density very important
Martin-Baltimore	Primarily shear - Some tension Some fatigue - Sonic vibration	Fuel corrosion	Mil Hbdk 5 + Fastener specs. (less 15%) D. A.
G. E. - Phila.	Primarily shear - Some tension No fatigue - Vibration "G" loads (12 max.)	High humidity - long duration - corrosion - Oxidizer and fuel corrosion Temp. limits -100° to +350° High vacuum - Radiation no concern	Mil Hbdk 5 modified D. A.
Space Tech. Lab	Both tension and shear + fatigue, vibration, impact	Temp. limits for internal spacecraft fasteners 30° to 95°F - External limits -250 to +250°F - Outgassing problems fuel corrosion on engines	Mil Hbdk 5 + analysis of critical applications for D. A. - Fasteners and structures must have compatible electrolytic potentials and thermal properties
Marshall Space Flight Center	Largely shear - All others in varying degrees. Increased magnitudes in future due to higher speeds and accelerations	Corrosion - Lox, seacoast, galvanic stress	Mil Hbdk 5 Safety factors 1.1 for yield 1.4 for ultimate strength/density only minor
McDonnell	All conditions of loading	Temp. limits -423° to +5000°F Galvanic and temp. corrosion unwanted bonding in vacuums	Mil Hbdk 5 + MAC 339 Want fasteners with good cryogenic 2nd elevated temp. properties together. Advocate "total joint" information
General Dynamics/ Astronautics	Some tension Combined tension & shear vibration, but not severe	-423°F to 600°F with expectations to 2700°F - corrosion - salt spray - vacuum & radiation hazards FLOX - LOX & LH_2	Mil Hdbk 5 formulated turn of the nut method

TABLE 7

TORQUE VS. INDUCED LOAD STANDARDS

Company	Standard	Remarks
Chrysler, New Orleans	ABMA 18 CCSD 60C06006	
Boeing, New Orleans	BAC-5009	Similar to HIAD
Marshall Space Flight Center	ABMA 18 MSFC10M 100515	
Martin, Denver	Martin generated values. Vendor TT curves	
North American, Downey	NA generated values	
North American, Canoga Park	NA generated values	Arthur H. Korn formula (Prod. Eng. Nov. 1943)
Lockheed, Sunnyvale	HIAD LAC generated values	
Boeing, Seattle	HIAD BAC generated data	
Thiokol, Elkton	Vendor supplied TT curves	
Martin, Baltimore	Martin generated values	Planning to use Bureau of Standards Handbook
G. E., Philadelphia	HIAD Vendor TT curves	
Space Technology Labs	HIAD	
McDonnell	HIAD Vendor TT curves	
General Dynamics/ Astronautics	Skidmore-Wilhelm Approach	

TABLE 8

PLATINGS AND COATINGS

1. Marshall Space Flight Center	Cadmium	Protection & lubricant on steel. Lubricant & galvanic barrier on stainless steel.
	Silver	Lubricant
2. Chrysler, New Orleans	Cadmium	Same as 1.
3. Martin, Denver	Cadmium	Lubricant & galvanic barrier on stainless steel.
	Silver	Lubricant
	Azorizing (Cr)	Wear resistance
4. North American, Downey	Cadmium	Same as 3.
	Silver	Lubricant
5. North American, Canoga Park	Silver	Lubricant
	Ni Cd	900° corrosion protection
6. Lockheed, Sunnyvale	Electrofilm	Lubricant
	Silver	Lubricant
7. Boeing, Seattle	Cadmium	Same as 3.
	Silver	Lubricant
8. Thiokol	Cadmium	Protection and lubricant on steel
9. Martin, Baltimore	Cadmium	Same as 1.
	Ni Cd	Same as 5.
10. G. E., Philadelphia	Cadmium	Same as 8.
11. Space Technology Labs	Aluminum	Thermal control
	Passivated	Corrosion
	Gold	Thermal Control
	Chromium	Wear resistance
	Silver	Lubrication & thermal control
12. McDonnell	Cadmium	Same as 1.
	Silver	Same as 1.

application and for this reason are not commented on further. Table 9 lists the various types of lubricants.

5. Installation Problems

Very few companies indicated that they had any serious installations problems. Several firms did say that galling of A-286 and high nickel alloy fasteners presented an installation problem. This indicates that more work is needed in lubricant development or at least proper utilization of available lubes. Mention was made of inconsistent preloading which ties in with lubrication and lends weight for the need to establish standard torque tension methods and conditions of testing.

One other problem concerned wrenchability of internal wrenching parts and 12 point external drives. Investigations in this area are presently in progress by the Naval Air Engineering Center (NAEC), Philadelphia Navy Yard.

6. Design Allowables

Almost without exception MIL Handbook Five was a source for this data, but also without exception, company manuals supplemented Handbook Five. Most concerns felt the need to be more conservative and discount some of the data for their use.

7. Weight and Space Considerations

The majority of replies to questions on this subject indicated consideration for high strength-to-density ratios in design, mainly because of vehicle weight criticality.

E. TESTS AND TEST METHODS

It is reasonable to conclude that there are gaps in the overall knowledge of fastener properties and performance under specified conditions. Accordingly, a number of suggestions were made as to how these gaps should be filled by the generation of new or improved tests and test methods. Recommended new or improved tests are shown in Table 10.

F. FASTENER INFORMATION

Specifications governing the procurement of fasteners usually lag well behind their introduction and use. In the case of NAS and MS specifications and drawings the time gap can run anywhere from two to five years. Consequently, a void is created which must be filled and usually is by the fastener manufacturer. As the users continue to purchase a product, the user's requirement for a specification grows and it is generally obtained by lifting portions almost word for word from the manufacturer's specification.

TABLE 9

LUBRICANTS

Company	Type of Lubricant	Remarks
Chrysler, New Orleans	Moly Kote Z Dow Corning FS1280 & 1281 Grease Teflon Other MoS_2	
Martin, Denver	Dri Lube 842 Dri Lube 701 Silver Fluorocarbon Paste Wax	
North American, Downey	North American MoS_2	
North American, Canoga Park	Silver Dri Lube 701 Kel F 90 LOX - Lube	450° - 1200°F -423° - 450°F
Lockheed, Sunnyvale	Electrofilm Silver MIL-L-8937	
Boeing, Seattle	Silver "goop" Silver BMS 3-3 (MoS_2)	
Thiokol	MIL-T-5544 MoS_2	
G. E., Philadelphia	MoS_2	As supplied on parts by vendors
Space Technology Labs	Everlube 811B Micro Seal Teflon Metal Powders in Resins Graphite	
McDonnell	MoS_2 Teflon	
General Dynamics/ Astronautics	Oxylube 702 & 703 Lox Safe Kel F 90	Compatibility with LOX Expected future problems with compatibility with FLOX

TABLE 10

RECOMMENDED NEW OR IMPROVED TESTS

Boeing-New Orleans	Relaxation - residual stress
Martin-Denver	Vibration of locknuts
North American-Canoga Park	Fatigue, elongation at .2% yield
LMSC	Yield strength A-286, torque tension
Boeing-Seattle	Torsion-Shear, elevated temperature test fixtures
Martin-Baltimore	Torque tension, vibration of locknuts
G. E. - Philadelphia	Yield strength
Space Technology Labs	Torque tension, magnetic permeability
Jet Propulsion Labs	Magnetic permeability
Lewis Research Center	Vibration
Republic	Vibration, thermal cycling, creep
McDonnell	Stress durability, elevated temperature, relaxation, vibration of locknuts, elevated fatigue, metallographic check after temperature
General Dynamics/Astronautics	Effects of rapidly applied loads of short duration at low temperatures, corrosion resistance under load

The fastener manufacturers who responded to the request for their recommendation of fasteners to be evaluated in the test program are listed in Table 11. Included are the materials and configurations of fasteners they presently supply to the aerospace industry.

G. LITERATURE SURVEY

In addition to the user survey, a continuing literature survey of materials was conducted to collect available fastener data and materials data for evaluating potential fastener utilization. The survey included materials within the base alloy groups of iron, nickel, cobalt, titanium, and aluminum. Final selection of materials for inclusion in the program was based on the user's survey, available fastener data, DMIC memorandums, supplier information, high strength considerations, and NASA reports and information. During the past year the following alloys were investigated.

Iron Base	Nickel Base	Cobalt Base	Titanium Base
AISI H-11	Inco 718	L-605	Ti-6Al-4V
Vasco Max 300	Waspaloy		Ti-5Al-2.5Sn
A-286	AF 1753		Ti-1Al-8V-5FE
U-212	Udimet 700		Ti-8Al-1V-1Mo
AFC 77	Monel		Ti-7Al-12Zr
	Rene 41		
	Rene 62		
	Udimet 630		

1. Iron Base Alloys

a. AISI H-11

AISI H-11 alloy is a high strength 5 per cent chromium tool steel employed in the fabrication of precision fasteners for the aerospace industry. Minimum ultimate strength of 260 ksi with good ductility can be obtained with H-11 material at room temperature. At present, the temperature range for this material is from room to 900°F applications. However, data have been generated on the cryogenic properties of fasteners down to -320°F (Ref. 1). Short-time tensile tests show an increase in strength with decreasing temperature with a slight decrease in ductility at -320°F.

Standard charpy impact results indicated that a ductile to brittle transition occurs around -100°F; however, similar tension impact results of bolt threads do not correlate with these findings. The energy required to fracture a 1/4-28 bolt thread was essentially the same at -320°F as at 70°F.

TABLE 11

FASTENER MANUFACTURERS CONFIGURATIONS & RECOMMENDATIONS FOR EVALUATION

Company	Fastener Type	Material	Specifications (applicable)	Recommendations
Elastic Stop Nut Corporation	Self Locking Nuts			
	NAS 3250	Alloy Steel	NAS 3350	for use to 450°F
	MS21084 & MS21085	Alloy Steel 220 ksi thru 260 ksi	MIL-N-8922	for use to 450°F
	Alma Project 46	A-286	Alma Spec. 12	-423°F to 800°F
	Alma Project 29	Waspaloy-Rene 41 and M-252	AMS 2410	-423°F to 1600°F
			Alma Project 29	Use Esna lube 382 for application 1200°F through 1600°F
Huck Manufacturing Company	Blind Bolt	A-286	Not Included	-
	S3L Lockbolt	A-286	Not Included	-
	MLS Blind Rivet	Monel & 17-4 PH	Not Included	-
	SAL Lockbolt	Ti-6Al-4V	Not Included	-
	ALP Lockbolt	Ti-6Al-4V	Not Included	-
Townsend Co. Cherry Rivet Div.	Blind Rivet	Al Alloy	NAS 1400	to 250°F
	Blind Rivet	A-286	NAS 1400	to 1200°F
	Blind Rivet	Al Alloy	Cherry Rivet	to 250°F
	Blind Rivet	Monel	Cherry Rivet	to 900°F
	Lock Bolt	Alloy Steel	NAS 1413	to 800°F
	Lock Bolt	Aluminum	NAS 1413	to 250°F
	Lock Bolt	A-286	Cherry Rivet	to 1200°F
Valley Bolt Corp.	12 Pt. & Hex Hd.	A-286 160 ksi Ftu thru 200 ksi Ftu	VA1-6450, 6650 & 6750	-423°F to 1200°F for Nuclear
	12 Pt. EWB	Waspaloy 220 ksi thru 260 ksi	VA1 - 6822	Cryogenic Application
	12 Pt. & Hex Hd.	Waspaloy 180 ksi - Ftu	VA1 - 3800	Room to 1600°F
	12 Pt. EWB	17-4 PH 200 ksi - Ftu	N/A	Exotic Fuel Areas
	12 Pt. EWB	15-7 Mo 220 ksi - Ftu	N/A	Exotic Fuel Areas Hi Strength
	12 Pt. hex hd. &specials	H-11 220 ksi thru 260 ksi	VA1 6220, 6260, 6820, 4260	Various
	12 Pt. EWB & speicals	Mar-aging 250 ksi	N/A	Cryogenic to 800°F
Voi-Shan Manufacturing Company	The Voi-Shan Co. did not specify any specific type of fasteners, but recommended general types of fasteners that should be considered. These consisted of Hi Lok Bolts, Hi Shear Rivets, Huck Lok Bolts and similar types of fasteners. The materials they recommended were high strength to nickel base and ferrous nickel alloys such as tensilized A-286, Waspaloy, Inconel 718 and similar alloys. They also mentioned titanium alloys for cryogenic and higher temperature exposures.			
Standard Pressed Steel Company	The fasteners supplied by SPS to the Aero Space Industry are many and varied. The list presented here represents a select few that they feel should be evaluated in this program.			
	EWB 922	H-11 220 ksi	SPS M107 AMS 2416	for use to 900°F
	EWSB 926	H-11 260 ksi	SPS M107 AMS 2416	for use to 900°F
	FN 922	H-11 220 ksi	SPS M107 AMS 2416	for use to 900°F
	EWSN 926	H-11 260 ksi	SPS M107 AMS 2416	
	EWB 0420	A-286 200 ksi	AMS 5735	for use to 1200°F
	EWB Hi Ti 20	1-8-5 Ti 200 ksi	SPS M174	for use to 300°F
	EWBT 815	7-12 Ti 150 ksi	SPS M179	for use to 750°F
	EWB 1218	U-212 180 ksi	SPS M134	for use to 1200°F
	EWB 1615	Waspaloy 150 ksi	SPS M175	for use to 1600°F

From the limited amount of information available, a more thorough evaluation of H-11 for cryogenic fastener application to -423°F was considered justifiable. Also, the H-11 fasteners would provide a comparison standard for the performance of other materials under unique environment or tests investigated during the program. Therefore, tension and shear bolts and companion fasteners of H-11 were selected for fastener evaluation in this program.

b. Vasco Max 300

The maraging steels, particularly the 18 per cent nickel grade with cobalt and molybdenum, are receiving extensive consideration for non-corrosion resistant, low temperature application. The various steel producers report this material to have high ultimate and yield strengths with excellent ductility and notched to unnotched ratios. They state that this material possesses superior hot and cold workability, ease of heat treatment, weldability and adequate impact properties at cryogenic temperatures which would make it a suitable material for wide applications in existing and experimental engines, air frames and missile systems (Refs. 2, 3 and 4).

An evaluation by SPS of maraging steel as a possible material for high strength cryogenic fastener application showed tensile and yield strengths of bolts and specimens increased significantly with decreasing temperatures with very little change in ductility. Ultimate strength at -320°F was on the order of 350 ksi with 10 per cent elongation. At present, the temperature range for this material (Ref. 5) is from -320°F to 900°F.

c. A-286

Conventional A-286 alloy is one of the prime materials used for cryogenic and moderate to high temperature applications. There appears to be more data available on the -423°F properties of A-286 than any other heat and corrosion resistant material. The National Aeronautics and Space Administration reports that A-286 material is recognized as an invaluable material for fasteners at cryogenic and elevated temperatures. However, in the extremely cold worked condition its application is limited (Ref. 6). A-286 exhibits good elevated temperature properties to 1200°F which gives this material a utilization range of -423°F to 1200°F. High strength A-286 (200 ksi) was selected for fastener evaluation in the program.

d. U-212

The National Aeronautics and Space Administration also concluded from tests of U-212 fasteners that this material shows considerable promise as a low temperature fastener material but that the material cost is relatively high compared to A-286 alloy (Ref. 6). Applications for U-212 alloy would be the same as for A-286. U-212 was selected for evaluation as a potential high strength fastener material.

e. AFC 77

AFC 77 alloy is a high strength, elevated temperature stainless steel developed by the Crucible Steel Company under an Air Force contract. Depending on the heat treatment employed, AFC 77 appears to have either potential cryogenic or high temperature application to 1200° F. Although AFC 77 exhibits high strength at -320° F, it was not considered for evaluation because of low ductility in comparison to those materials selected.

2. Nickel Base Alloys

a. Inconel 718

Available information procured from the steel producer literature indicates this material possesses excellent cryogenic properties to -423° F (Ref. 7). Tensile strengths on the order of 260 ksi with 15 per cent elongation were recorded at -423° F. Evaluation of Inco 718 as a fastener material also shows it to exhibit excellent elevated temperature properties to 1200° F. Inconel 718 was selected for evaluation as a potential high strength fastener material in this program.

b. Waspaloy

Waspaloy alloy is another of the nickel base alloys that appears to have the potential for cryogenic fastener application. Data on the -423° F properties of Waspaloy were confined mostly to charts illustrating a comparison to U-212 and A-286. Notched to unnotched tensile ratio was higher at -423° F (.86) than at 70° F (.81) for a notch stress concentration factor of K_t 10. Tensile strength of specimens increased appreciably with decreasing temperature (Ref. 6).

Waspaloy was developed for high temperature application to

1600°F. Existing fastener data show it to possess good short time elevated temperature properties to 1600°F. Therefore, the potential temperature range for this material as a fastener appears to be from -423°F to 1600°F. Standard Waspaloy was selected for fastener evaluation while cold reduced Waspaloy was selected for evaluation as a potential high strength fastener material in the test program.

c. AF 1753

The Air Force completed a program which developed the alloy AF 1753 which shows good potential for fastener use as high as 1800°F. Material data on this nickel base alloy indicate a possibility for cryogenic utilization. AF 1753 has the highest strength of the so-called super alloy series. Fastener data generated by SPS show it to possess good elevated temperature properties to 1600°F (Ref. 8). Because of these attributes, AF 1753 has been selected for future evaluation as a potential high strength fastener material in 1965.

d. Udimet 700

Udimet 700, and its modification known as Astroloy, is another of the highly alloyed nickel base super alloys. Although there is no data to support it, this material, a nickel base alloy, probably will exhibit good cryogenic properties to -423°F. Available fastener data show it to have good elevated temperature properties to 1600°F (Ref. 9). In general, U-700 is stronger than the run of the mill super alloys of Rene 41, M-252, Waspaloy, and U-500. U-700 and Astroloy are not being considered for evaluation because they are not commercially available at the present time.

e. Monel

Monel was investigated because of the possibility of making rivets and other cold deformable type fasteners. This alloy consists of a series of nickel-copper base alloys known to have excellent corrosion resistance. The temperature range of the material appears to be from -423°F to 1800°F. Impact and tensile tests show monel increases in strength as the temperature decreases. There is no apparent ductile to brittle transition down to liquid hydrogen temperature. However, monel was not considered for evaluation because it is not considered applicable for NASA needs because of low strength.

f. Rene 41

The alloy Rene 41 is another of the nickel base super alloys. It was developed by the General Electric Laboratories for high temperature structural usage. Fasteners of Rene 41 have been in application since late 1958.

Because Rene 41 is over six years old, there is a wealth of fastener and material data available including an Air Force study on the effect of creep-exposure on the mechanical properties (Ref. 10).

Available cryogenic data for Rene 41 show that the notch ratio (K_t 6.3) increases while ductility decreases (Ref. 11). Nonetheless, this material appears to have good potential from -423°F to 1600°F temperatures and was selected for future fastener evaluation in 1965 under this contract.

g. Rene 62

Rene 62 is a nickel base precipitation hardening super alloy developed by the General Electric Company (Ref. 12). Maximum applicable temperature is reported to be 1500°F, but could probably be used for higher temperatures in limited applications. Interest has been focused on the material because of its high strength obtained through heat treatment. Cryogenic application would also appear feasible because of its high nickel content. Rene 62 was not considered for evaluation because of its relative newness and uncertainty of availability from the suppliers.

h. Udimet 630

Udimet 630 is a vacuum induction melted precipitation hardening nickel base alloy with high tensile and yield strength over the range of 70°F to 1300°F. It is reported to have good notch ductility, cryogenic properties, and weldability. Tensile strengths on the order 300 ksi were obtained at -423°F with 7.0 per cent elongation which indicates that this material exhibits good potential from -423°F to 1300°F (Ref. 13). Based on these findings, Udimet 630 was selected for future evaluation as a potential high strength fastener material in 1965 under the present contract.

3. Cobalt Base Alloys

a. L-605

The alloy L-605 is a cobalt base, high temperature alloy also known as Haynes Alloy No. 25. The temperature range appears to be from -423°F to 1800/2000°F depending on the application.

Tensile and notched tensile data at -423°F show L-605 in the 20 per cent cold reduced condition to have high strength with excellent ductility and good notched to unnotched tensile ratio (Ref. 11). Smooth and notched (K_t 6.3) tensile strengths at -423°F were on the order of 260 ksi with 20 cent elongation.

In addition, the corrosion resistance of L 605 appears very good and the alloy can be used without a protective coating.

L-605 alloy with 30 per cent cold reduction has been selected for future evaluation as a potential high strength fastener material in 1965 under the present contract.

4. Titanium Base Alloys

a. Ti 6Al-4V

Ti 6Al-4V is an alpha-beta titanium alloy which has had extensive use in pressure vessel application down to -320°F. Interest is being focused to extend the useful temperature of application to -423°F for liquid hydrogen application.

The results of tests by the Astronautics Division of General Dynamics for TMCA show 6-4 Ti to have a pronounced increase in strength as temperature decreases (Ref. 14).

In addition, 6-4 Ti retains reasonable elongation and notch strength (K_t 6.3) when the temperature decreases to -423°F, if the oxygen level is controlled. However, all testing has been performed on sheet material with primary interest in pressure vessel applications. Because of their wide use in aerospace applications, tension and shear bolts of 6-4 Ti were selected for fastener evaluation in the test program.

b. Ti 5Al-2.5SN (Standard and ELI Grade)

Ti 5Al-2.5Sn is an all alpha non-heat treatable titanium alloy developed by TMCA. It is reported to have excellent properties in the temperature range of -423°F to 800°F. It has been used principally for pressure vessels and cryogenic fuel tanks. The useful application of this material has been extended down to LH_2 temperature by the lowering of the interstitial content which also increases toughness at low temperatures (Ref. 15).

A tensile strength of 240 ksi with 15 per cent elongation was obtained with 5-2.5 Ti material at -423°F temperature.

Data available on the fastener properties consist of stabilization tests which indicated mechanical properties are not affected after exposure at 800°F. From this, it appears that the 5-2.5 Ti has a useful utilization range of -423°F to 800°F. Therefore, standard 5-2.5 Ti was selected for future fastener evaluation and 5-2.5 Ti ELI grade was selected for future evaluation as a potential high strength fastener material in 1965 under this contract.

c. Ti 1Al-8V-5Fe

Ti 1Al-8V-5Fe is an alpha-beta titanium alloy that can be heat treated to 200 ksi minimum tensile strength at room temperature. It has been developed primarily as a fastener material for room temperature applications with a maximum applicable temperature of 300°F. Cryogenic properties of 185 Ti are non-existent and investigations in this area would be justifiable because of the high strength exhibited at room temperature. Ti-1-8-5 was selected for evaluation as a potential high strength fastener material in this program.

d. Ti 8Al-1V-1Mo

The 8-1-1 titanium alloy has recently come into national prominence as a leading candidate alloy for the supersonic transport. It has the highest modulus and lowest density of the commercially available titanium alloys (Ref. 16). It is an all-alpha titanium alloy requiring no solution treatment and age.

Cryogenic data of 8-1-1 Ti show that as the temperature decreases from room temperature to -423°F the notch ratio decreases considerably. The tests were conducted employing a notch factor of K_t 6.3 which is normally used to evaluate fastener potential. If the ratio of notched to smooth bar falls below 1.0, the future of the material for fastener utilization appears limited. This could be the case with 8-1-1 Ti.

Since 8-1-1 Ti is an all-alpha alloy, elevated temperature properties are good to 750°F. In addition, the material remains relatively stable after long exposures at 750°F. However, fatigue life decreases as a result of long-time exposures.

In light of the limited amount of cryogenic properties on 8-1-1 Ti, it was selected for future fastener evaluation in 1965 under the present contract.

e. Ti 7Al-12Zr

The 7-12 titanium alloy is presently used in the fabrication of fasteners for elevated temperature application to 750°F. It is a super-alpha titanium alloy requiring no solution treatment and age. Since it was developed for high temperature fastener application, stability of this material is relatively good after long exposures at 750°F although loss in fatigue life has been noted after long exposure at 750°F.

Cryogenic properties of 7-12 Ti are non-existent, but the potential as a cryogenic fastener material appears to be present. Therefore, 7-12 Ti was selected for fastener evaluation in the test program.

MATERIAL SURVEY

REFERENCES

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(2) Special Metals, Inc. Technical Release "Alloy Performance Data - Minimum Properties Guarantees of Udimet B (18% Nickel Steel)" (1962)

(3) International Nickel Co., Inco Technical Release "Preliminary Technical Data on the Mar-aging Nickel Steels" (June 1962)

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(6) J. W. Montano "Low Temperature Mechanical Properties of 'Unitemp' 212 Alloy" Engineering Material Branch, Propulsion and Vehicle Engineering Division, George C. Marshall Space Flight Center (Jan. 1963)

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(8) J. Glackin - "Comparison of the Mechanical Properties to 1600°F of Refined Grain AF 1753 versus Standard AF 1753 Material". SPS Laboratory Report No. 943

(9) E. F. Gowen, Jr. - "Evaluation of Udimet 700 As a 1600°F Fastener Material" SPS Lab Note No. 93

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(11) Paul H. Denke - "Problems in Selecting Alloys For The Supersonic Transport" Metals Progress, March 1963, pp 70-76

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(15) TMCA - Titanium Data for the Aerospace Industry

(16) Aerospace Structural Metals Handbook, Volume II, Code 3709

SECTION III

PHASE II - FASTENER EVALUATION

As a result of the survey undertaken in Phase I, twenty-one different classes of fasteners were selected for evaluation by the contracting officer's technical representative. These fasteners include variations in tensile and shear bolts, blind bolts, structural rivets, and companion nuts. Listed in Table 12 are the types of fasteners, materials, strength levels, and sizes that were evaluated. Table 13 lists the procurement specification while Table 14 shows the nominal composition of the fasteners. Pictorial representation of the various fasteners is included in Figures 1, 2, 3 and 4.

A. PROCUREMENT

Listed also in Table 12 are the various suppliers who supplied fasteners for evaluation in addition to SPS. These manufacturers currently supply the aerospace industry. In addition, other fastener manufacturers were requested to submit price and delivery quotes for specific fasteners to be evaluated in the program. Many chose not to quote.

The 3/8-24 A-286 point drive bolt and companion twist-off nut was dropped from the test program because it is still in the development stage and is unavailable at the present time.

TABLE 12

SELECTED FASTENERS FOR EVALUATION IN PHASE II

Class	Size	Description	Material	Min. U. T. S. @70°F-KSI	Max. Utilization Temp°F	Supplier
1	#10, 1/4, & 1/2	12 Pt. Tension Bolt	AISI H-11	220	900	SPS
2	#10, 1/4, & 1/2	12 Pt. Nut	AISI H-11	220	900	SPS
3	#10, 1/4, & 1/2	12 Pt. Tension Bolt	Waspaloy	150	1400	SPS
4	#10, 1/4, & 1/2	12 Pt. Nut	Waspaloy	180	1400	SPS
5	#10, 1/4, & 1/2	12 Pt. Tension Bolt	Ti 7Al-12Zr	150	750	SPS
6	#10, 1/4, & 1/2	12 Pt. Tension Bolt	Ti 6Al-4V	160	400	Voi-Shan
7	#10, 1/4, & 1/2	12 Pt. Nut	A-286	160	1200	SPS
8	#10, 1/4, & 1/2	12 Pt. Tension Bolt	A-286	200	1200	Voi-Shan
9	#10, 1/4, & 1/2	12 Pt. Nut	A-286	200	1200	Voi-Shan
10	#10, 1/4, & 1/2	12 Pt. Shear Bolt	AISI H-11	260	900	SPS
	#10, 1/4, & 1/2	12 Pt. Nut	AISI H-11	210	900	SPS
11	#10, 1/4, & 1/2	Hexagon Shear Bolt	Ti 6Al-4V	160	400	Briles
	#10, 1/4, & 1/2	Hexagon Nut	AISI 4027	160	450	SPS
12	#10, 1/4, & 3/8	Point Drive Bolt	Ti 6Al-4V	160	400	Hi Shear
13	#10, 1/4, & 3/8	Twist Off Nut	Al-2024	70	250	Hi Shear
14	#10, 1/4, & 3/8	Point Drive Bolt	AISI 8740	180	450	Hi Shear
	#10, 1/4, & 3/8	Twist Off Nut	Al 2024	70	250	Hi Shear
15	#10 & 1/4	Point Drive Bolt & Nut	A-286	140	1200	Hi Shear
16	#10	Jo Bolt	AISI 4130	70	450	National Screw
17	#10	Jo Bolt	A-286	70	1200	National Screw
18	1/8, 5/32, & 3/16	Semi Blind Rivet	Al 2017-T4		250	Townsend Co. Cherry Rivet Div.
19	1/8, 5/32, & 3/16	Semi Blind Rivet	A-286		1200	Townsend Co. Cherry Rivet Div.
20	1/8 & 3/16	Solid Rivet	Al 2024-T4		250	SPS
21	1/8 & 3/16	Solid Rivet	Pure Ti		500	SPS

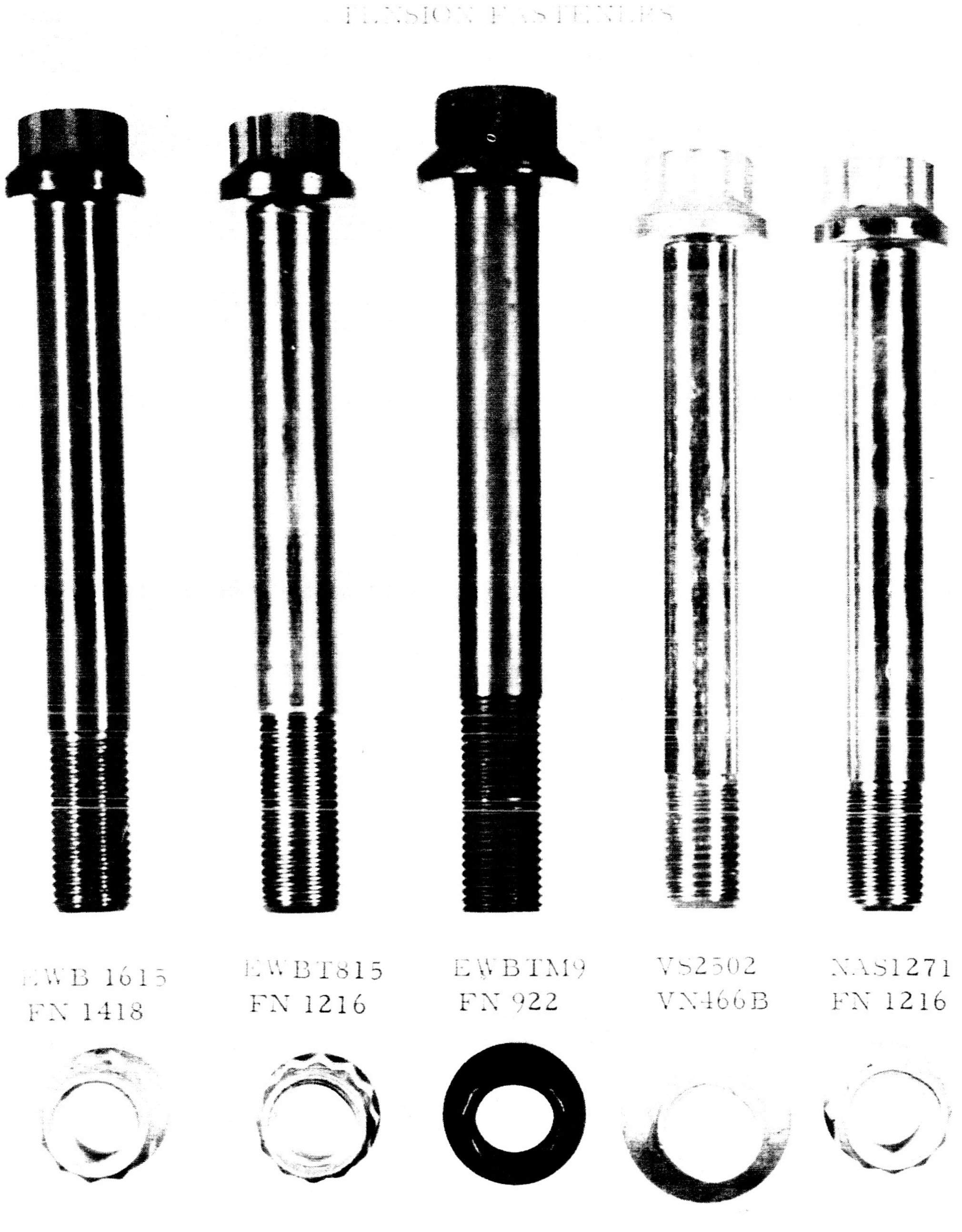


Figure No. 1 Composite Photograph of Tension Fasteners Evaluated in Phase II

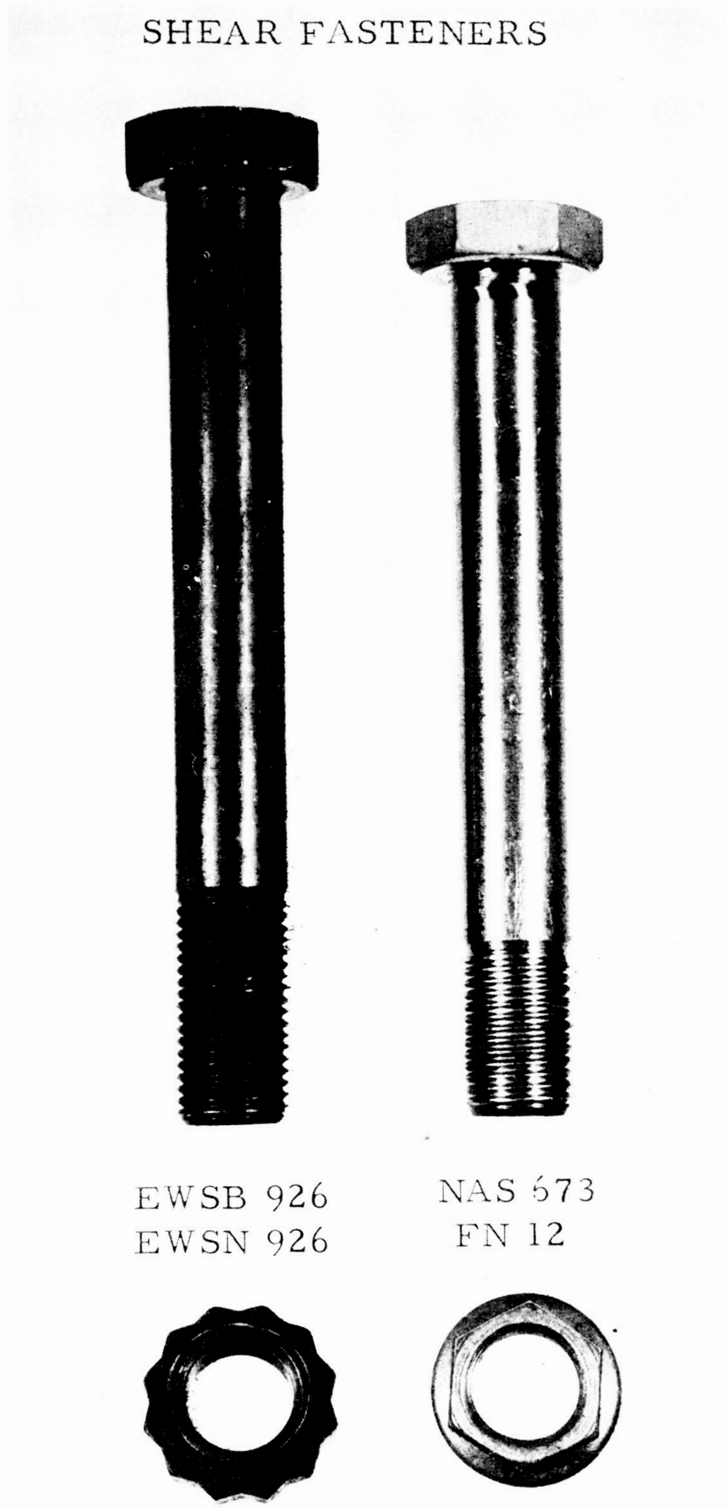
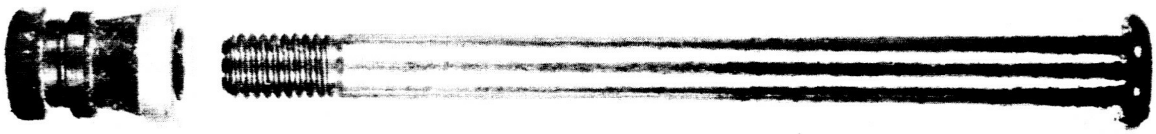


Figure No. 2 Composite Photograph of Shear Fasteners Evaluated in Phase II

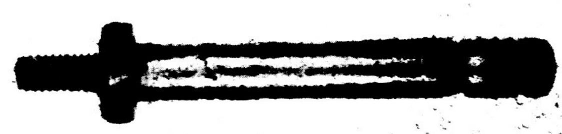
POINT DRIVE FASTENERS WITH TWIST OFF NUTS AND JO BOLTS

HL4078



HL10V70W

HL1870W

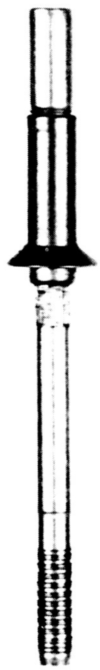


PP200-16

P200A-16

Figure No. 3 Composite Photograph of Point Drive and Jo Bolts Evaluated in Phase II

RIVET FASTENERS



Part No.
MS 20426 DD
Material
Al 2024-T4

Part No.
CR 2162
Material
Al 2017-T4

Part No.
CR2662
Material
A-286

Part No.
MS20426 DD
Material
Pure Titanium

Figure No. 4 Composite Photograph of Rivets Evaluated in Phase II

TABLE 13

FASTENER MATERIAL, MANUFACTURING & PLATING SPECIFICATIONS

Configuration	Material	Material Procurement	Manufacturing	Threads	Plating
Tension Bolts -					
EWB TM9	AISI H-11	SPS M-107B	SPS B106	MIL-S-8879	AMS 2416B
EWB 1615	Waspaloy	SPS M-175		MIL-S-8879(.003 Red. P. D.)	
EWBT 815	Ti7Al-12Zr	SPS M-179	SPS-B180	MIL-S-8879	
NAS 1271	Ti6Al-4V	NAS 621	NAS 621	MIL-S-7742	
VS 2502	A-286	AMS 5735E		MIL-S-8879	
Tension Nuts -					
FN 922	AISI H-11	SPS M-107B		MIL-S-8879	AMS 2416B
FN1216	A-286	AMS 5735E		MIL-S-7742	AMS 2410
FN 1418	Waspaloy	SPS-M-175		MIL-S-8879	AMS 2410
VS466B	A-286	AMS 5735E		MIL-S-8879	AMS 2410
Shear Bolts -					
EWSB 926	AISI H-11	SPS M-107B	SPS 109A	MIL-S-8879	AMS 2416B
NAS 673	Ti6Al-4V	NAS 621	NAS 621	MIL-S-7742	
EWSN 926	AISI H-11	SPS M-107B		MIL-S-8879	AMS 2416B
FN 12	AISI 4027	SPS M-187		MIL-S-7742	QQ-P-416
Point Drive Bolts -					
HL 10V	Ti6Al-4V	NAS 621	NAS 621	MIL-S-7742	
HL 18	AISI 8740	AMS 6322			QQ-P-416
HL 40	A-286	AMS 5735E		MIL-S-7742	
HL 70	Al-2024	QQ-A-430			MIL-A-8625 Anod. HiSH-305
HL 78	A-286	AMS 5735E			AMS 2410

TABLE 13 (continued)

Configuration	Material	Material Procurement	Manufacturing	Threads	Plating
Jo Bolts -					
PP 200	AISI 4130	MIL-S-6758			
PP 200A	A-286	AMS 5735E			QQ-P-416
Rivets -					
CR 2162	Al 2017 T4	QQ-A-430	NAS 1399D		
CR 2662	A-286	AMS 5735E	NAS 1399C		Dry Film Coating Cherry Spec. C-30
MS 20426	Al 2024 T4	AMS 4120	MS 20426		
MS 20426	Pure Ti	AMS 4921	MS 20426		

TABLE 14

MATERIAL NOMINAL COMPOSITION

Materials	C	Mn	P	S	Si	Ni	Cr	Mo	Ti	Co	Al	Cu	Zr	B	V	Fe	Cb & Ta	O_2	N_2	H_2
AISI H-11	.40	.30	.019	.007			4.98	1.29								Bal.				
Waspaloy	.042	.02		.004			11.65	4.44	2.99	13.46	1.26	.02	.062	.066	.54	.23				
Ti7Al-12Zr	.02	.02									7.1		12.1					.05	.03	.0047/.0057
Ti6Al-4V	.02								6.0		4.0					.15			.016	.0053/.0016
A-286	.06	1.5	.03	.02	.70	25.0	15.0	1.25	2.0		.30			.006	.30	Bal.				
AISI 8740	.40	.85	.04	.04	.30	.50	.50	1.25												
AISI 4130	.30	.50	.30	.20	.30	.20	.90													
Al 2024		.60			.15		.01		.01		Bal.	4.30				.23		Zn.05	Mg1.45	
Al 2017	.80	.70	Mg.50	Zn.25			.10				Bal.	4.0				1.0				
AISI 4027	.27	.80	.04	.04	.30			.25	Bal.											
Pure Ti	.08								Bal.									.28	.02	.0068

B. TEST PROGRAMS

The fasteners, shown in Figures 1 thru 4, evaluated in Phase II fall into three distinct categories; namely (1) tension and shear bolts with their companion nuts, (2) point drive and Jo bolts, and (3) structural rivets. Because of this, the fasteners were tested under three separate test programs which were tailored to reflect the specific function of the fastener. The test programs are shown in Figures 5, 6 and 7.

1. Tensile

Tensile tests to determine yield and ultimate strengths for bolts and companion nuts, and the ultimate strength of the blind and semi-blind fasteners were conducted at -423° F, room temperature, and maximum utilization temperature of the fastener.

In order to determine the effects of temperature on the properties of the base alloy from which bolts were fabricated, standard tensile test specimens made from the bolts were tested at the same three temperatures.

2. Shear

Double shear tests of bolts and single or lap shear tests of rivets were conducted at -423° F, room temperature, and maximum utilization temperature of the fastener.

3. Stress Rupture

Stress rupture properties for one, ten, and one hundred hours were determined for the tension and shear fasteners at their maximum applicable temperature.

4. Stress Relaxation

Stress relaxation properties were determined for ten and fifty hours employing two initial preloads at the maximum utilization temperature of the fasteners.

5. Nut Reuse and Galling Tendencies

Nut reuse and galling tendencies were determined simultaneously at room temperature after exposure to -423° F (LH_2), room temperature, and the maximum utilization temperature of the locknut. These tests were confined to the companion locknuts of the tension bolts.

6. Vibration

Vibration tests to determine the locking characteristics of the companion locknuts of the tension bolts and the point drive twist-off nuts were conducted in accordance with the ALMA #10 specification at room temperature. The companion nuts for shear bolts were not included in the nut test program because they were not selected as a specific class of fastener to be evaluated.

7. Torque versus Induced Load

Torque versus induced load tests were conducted at room temperature to determine the torsional yield strength of the tension and shear fastener combinations. These tests were conducted in conjunction with determining the initial preloads to be employed for the relaxation tests.

8. Corrosion Resistance

Corrosion resistant properties were determined under seacoast and accelerated salt spray atmospheric conditions with an attempt to correlate the results obtained from each source.

9. Thermal Cycling

The effects of thermal cycling on the mechanical properties of the fastener combinations and the bolt material were determined at room temperature after being subjected to two different sets of thermal cycling.

a. Room temperature to -423° F to room temperature

b. Room temperature to maximum applicable temperature to room temperature.

The parts were cycled twelve (12) times between room temperature and the extreme temperature.

10. As Relaxed

The effects of the fifty hour relaxation tests on the ultimate strength, yield strength, and shear strength of the fastener combinations were determined at room temperature.

11. Stem Retention

The stem retention of semi-blind rivets was determined at room temperature for the "As Received" and "As Cycled" assembled rivets.

12. Preload

The blind bolt preloads after installation were determined at room temperature for "As Received" and "As Cycled" assemblies.

TEST PROGRAM - PHASE II

BOLT AND NUT

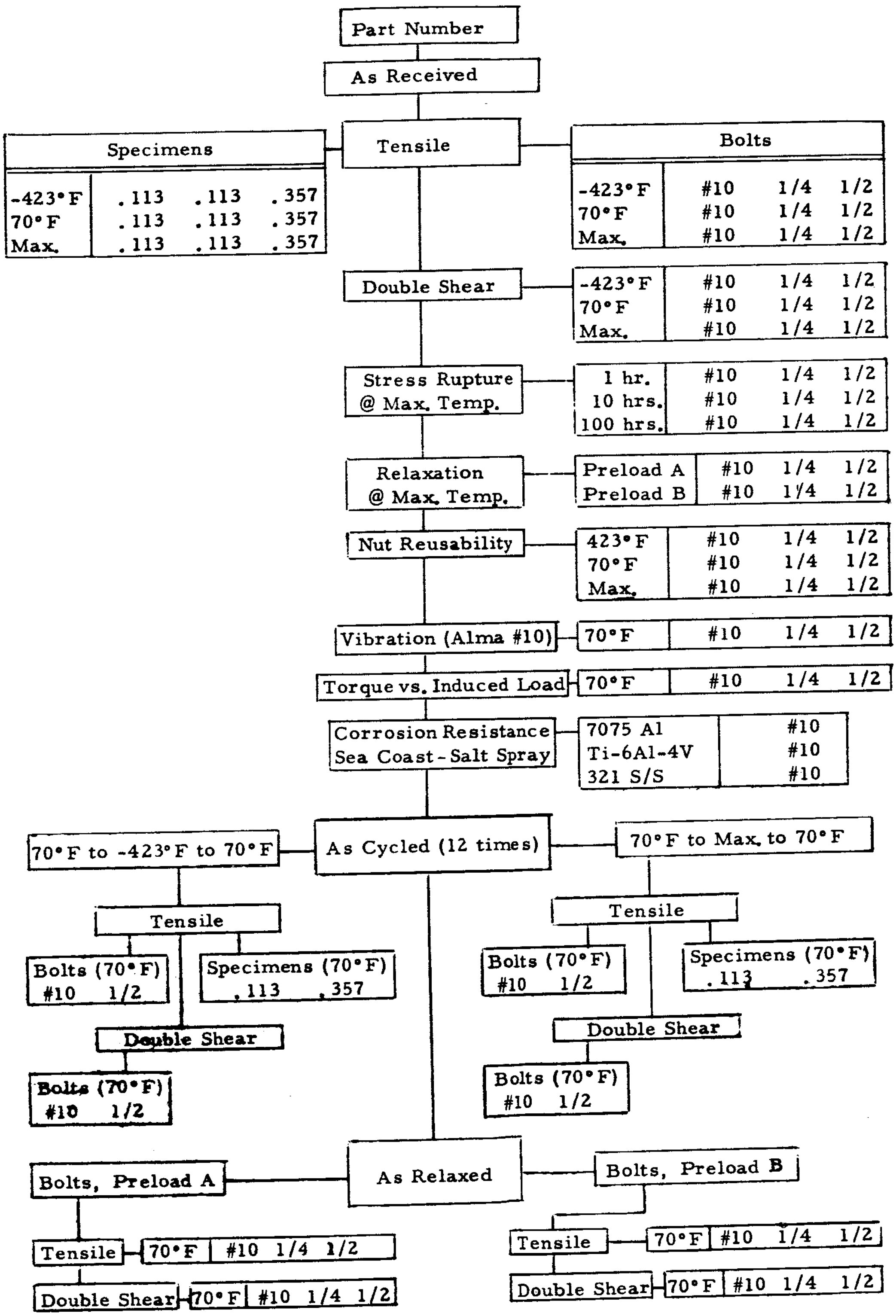


Figure 5

POINT-DRIVE BOLT AND NUT

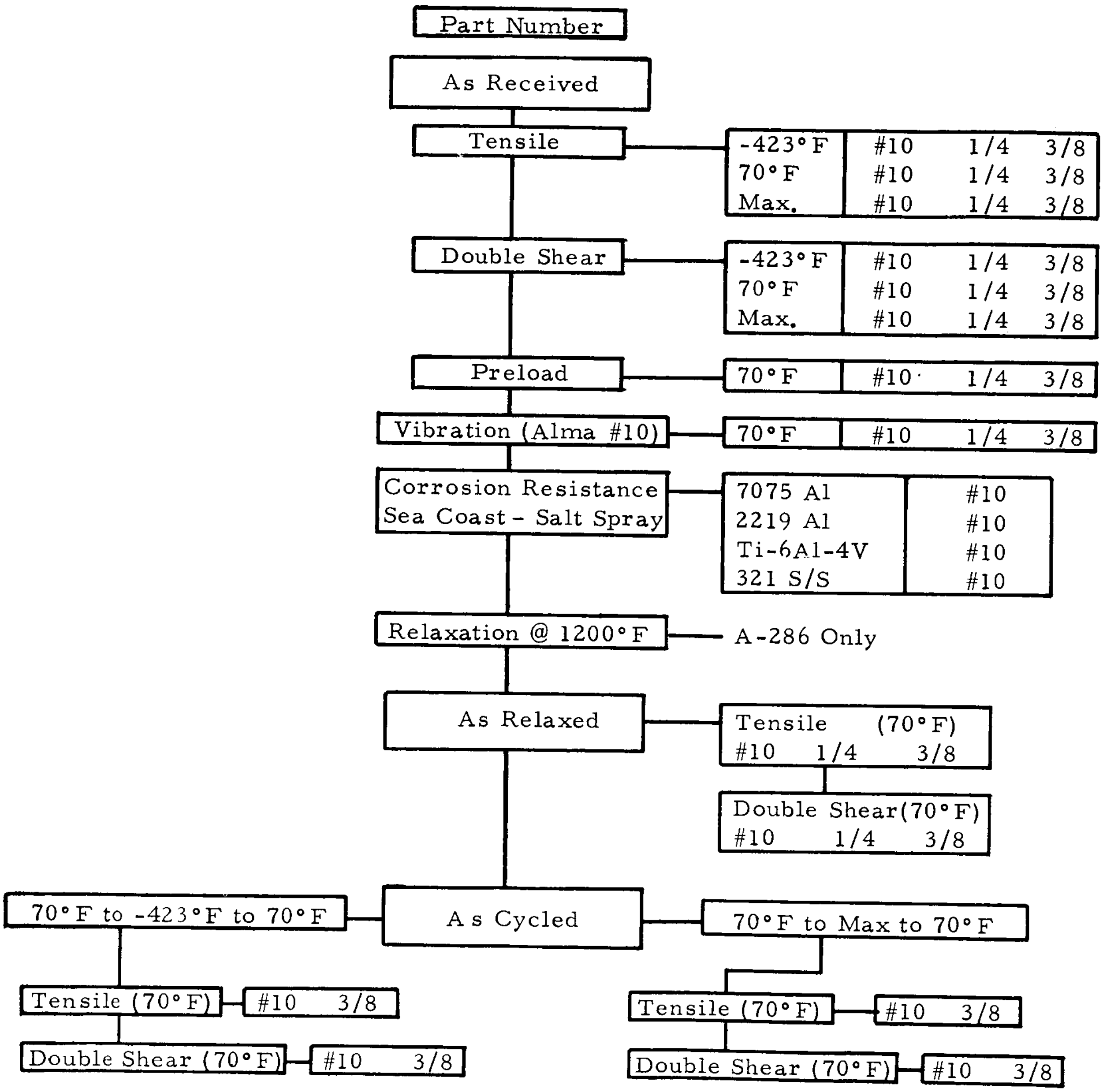


Figure 6

TEST PROGRAM PHASE II (continued)

RIVETS - MATERIAL

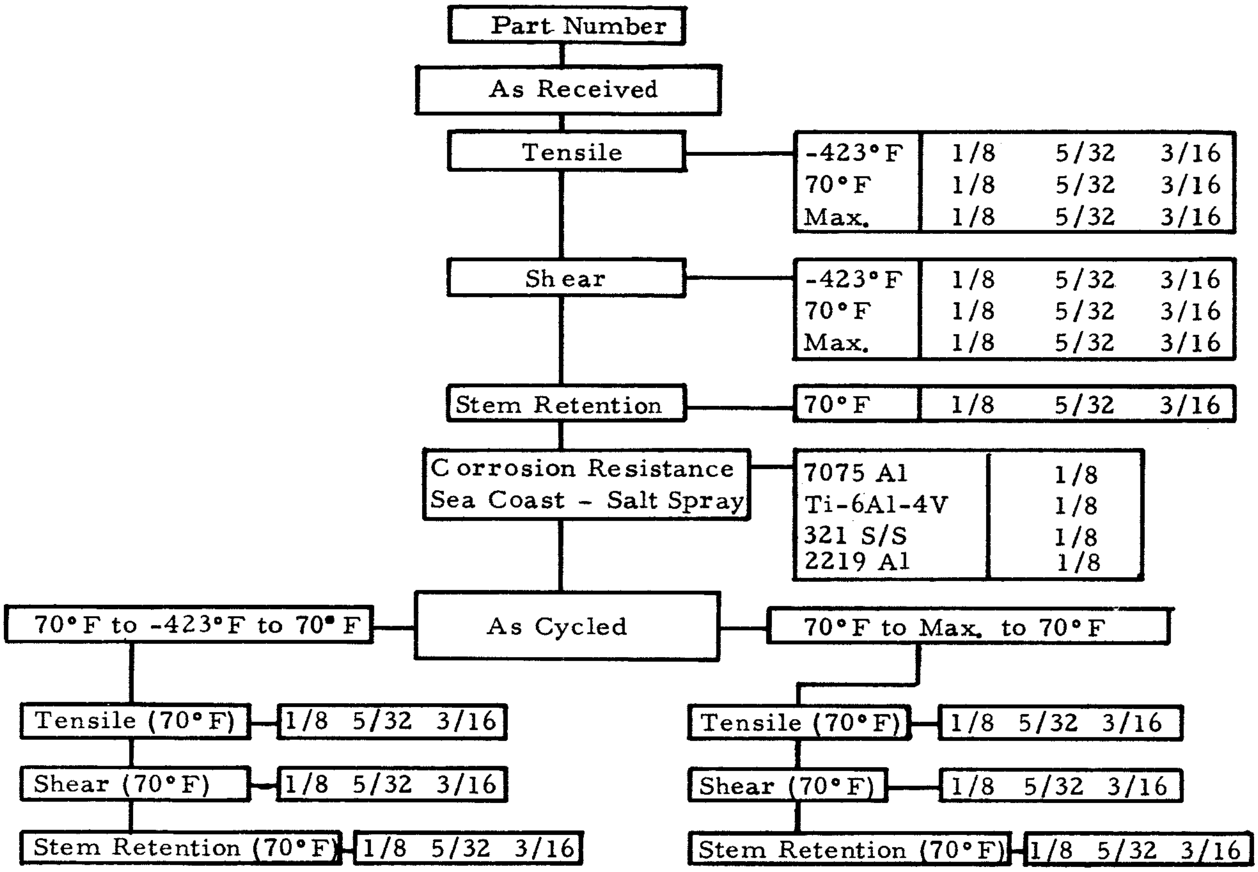


Figure 7

C. TEST PROCEDURES

1. Tensile

The tensile tests were conducted per ASTM E-8-61 T designation on the Tinius Olsen Universal Testing Machines employing a uniform loading rate of 65,000 psi per minute for bolts and .005 inches per inch per minute for specimens. For the bolt and companion nut tests, the nuts were assembled on the bolts leaving two to three threads exposed prior to testing.

a. Yield Strengths

Material yield strengths were determined by the 0.2 per cent offset method described in ASTM designation A 370-61 T. Bolt yield strengths were determined using Johnson's two-thirds approximate method. Figure 8 shows how these methods for determining yield strengths were accomplished.

Standard methods with the load extensometer attached to the test specimen were used for determining room temperature yield strengths. At cryogenic and elevated temperatures, alternate methods as shown in Figures 9 and 10 were used respectively for plotting stress-strain curves for the determination of yield strengths of bolts and specimens. In the case of cryogenic tests, the extensometer was attached to the undercut section of the .357 specimens and to the full shank of the .113 specimens. For bolts, it was attached to the bushing adapters at the bearing surfaces of bolt and nut. Preliminary tests at room temperature employing these methods in comparison to the standard method indicated no difference in yield strengths.

b. Elongation

The percentage of elongation was determined employing a .5 inch gage length for .113 inch specimens and 1.4 inches for .357 specimens.

c. Preload

Determination of room temperature preload and ultimate strength for the point drive and Jo Bolts was conducted, employing the fixtures shown in Figure 11. Prior to assembly shims were placed between the test fixtures at the joint surfaces. After bolt installation the loaded assembly was placed in the tensile machine and a uniaxial tensile

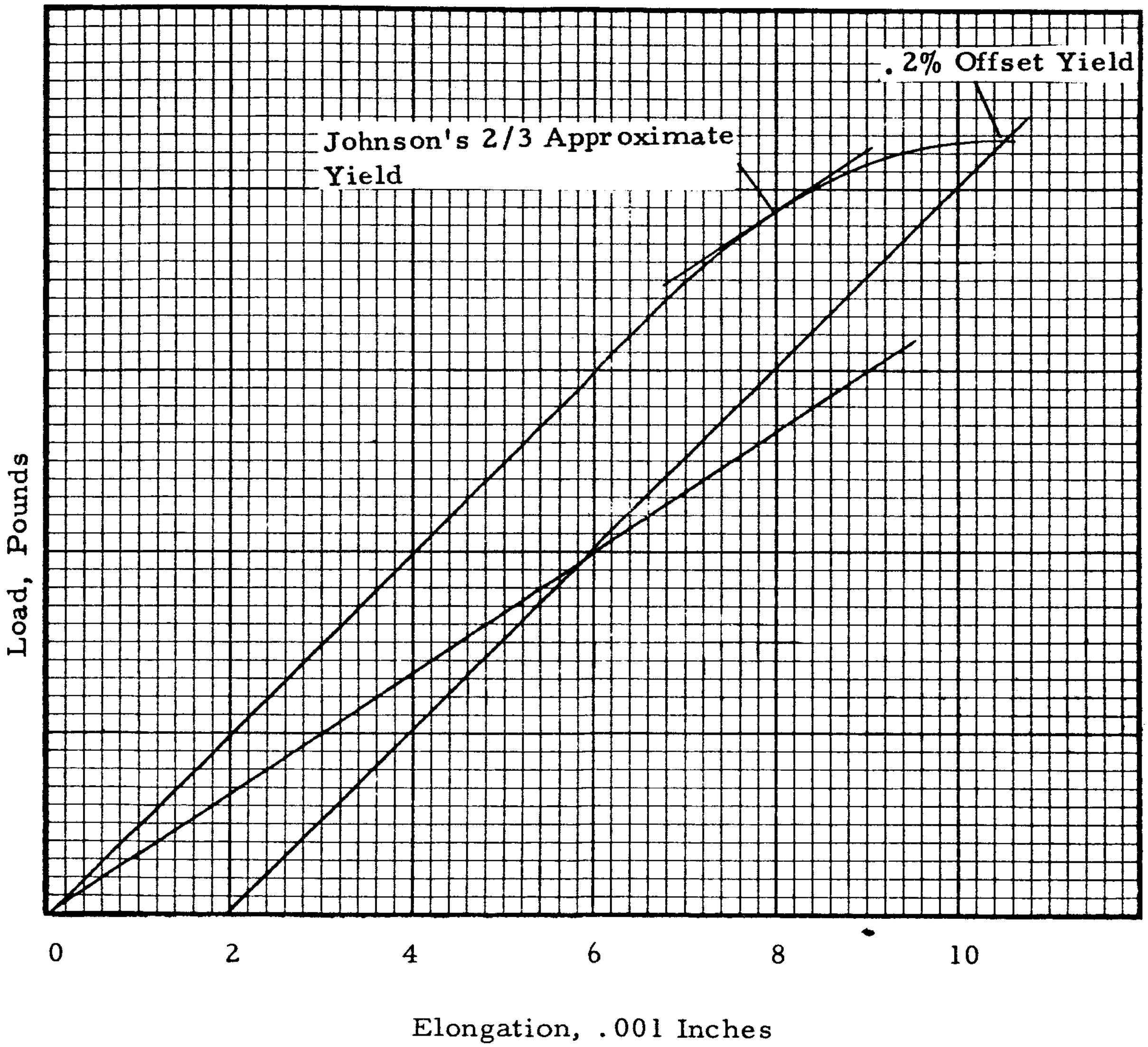


Figure No. 8 Two Yield Strength Determination Methods. Johnson's 2/3 approximate yield method is used for bolt yield determination and .2% offset yield is used for material specimen yield determination.

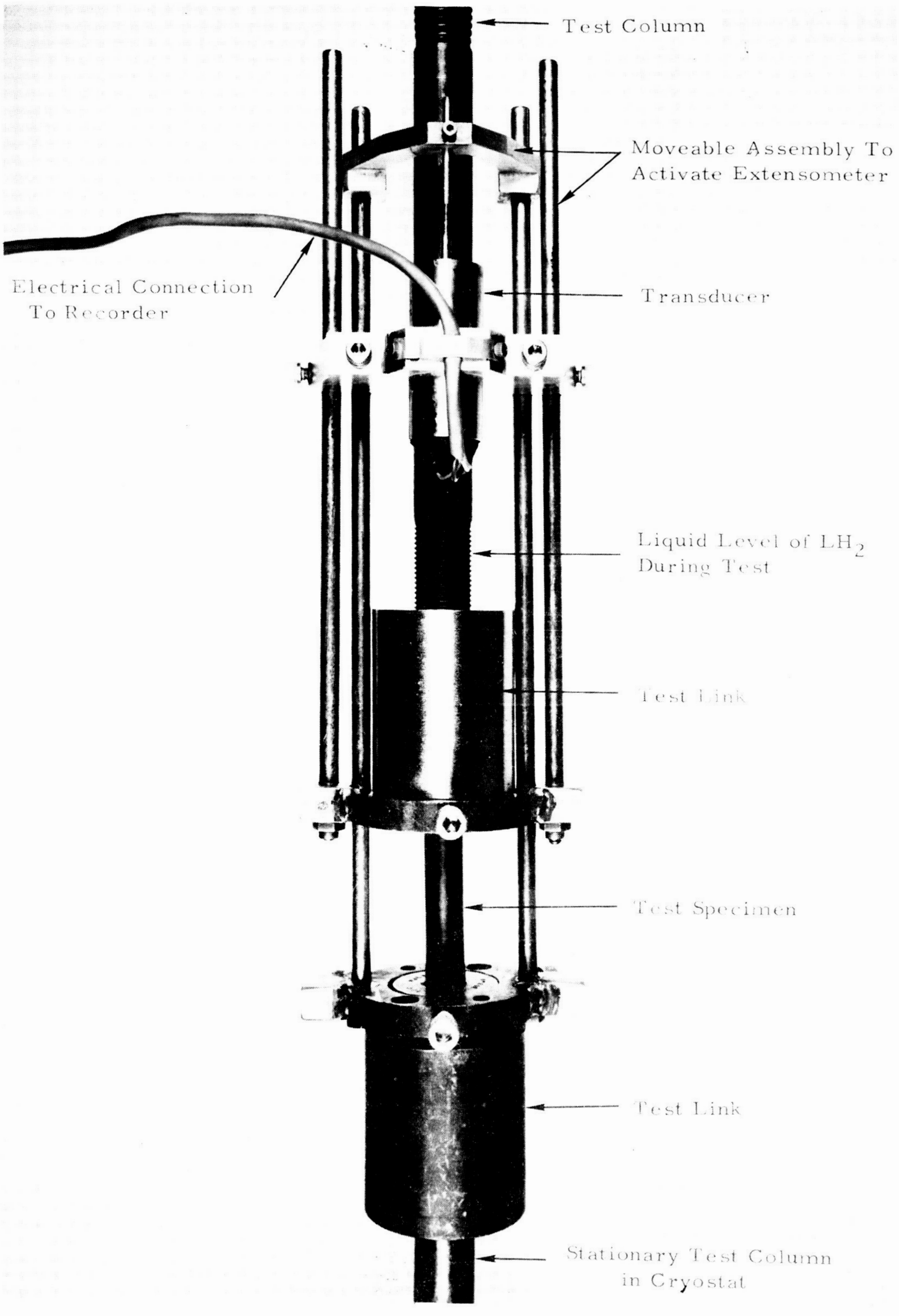


Figure No. 9 Load Extensometer Used for Plotting Stress-Strain-Curves at -423° F

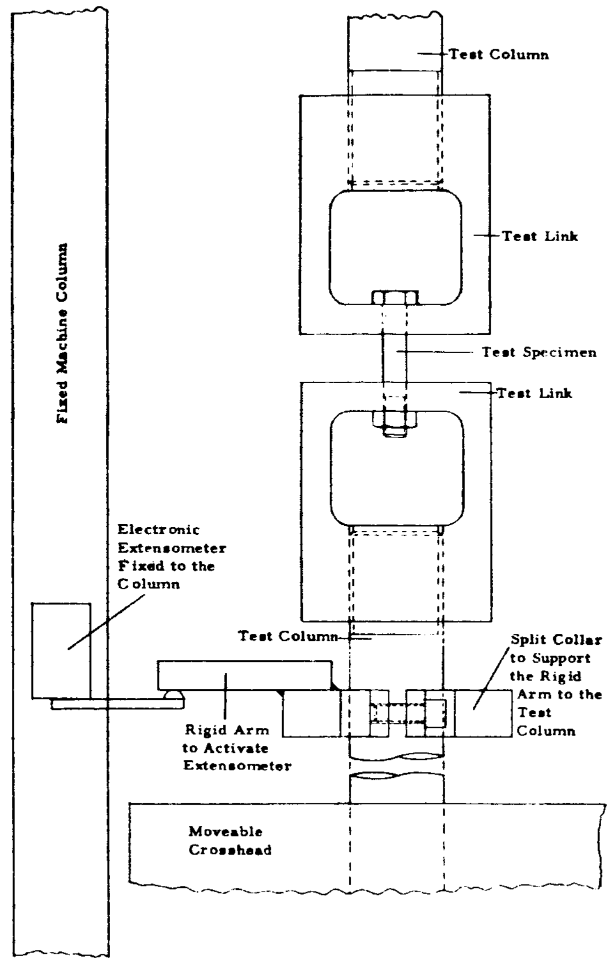


Figure No. 10 Alternate Stress-Strain Plotting Method for Elevated Temperatures.

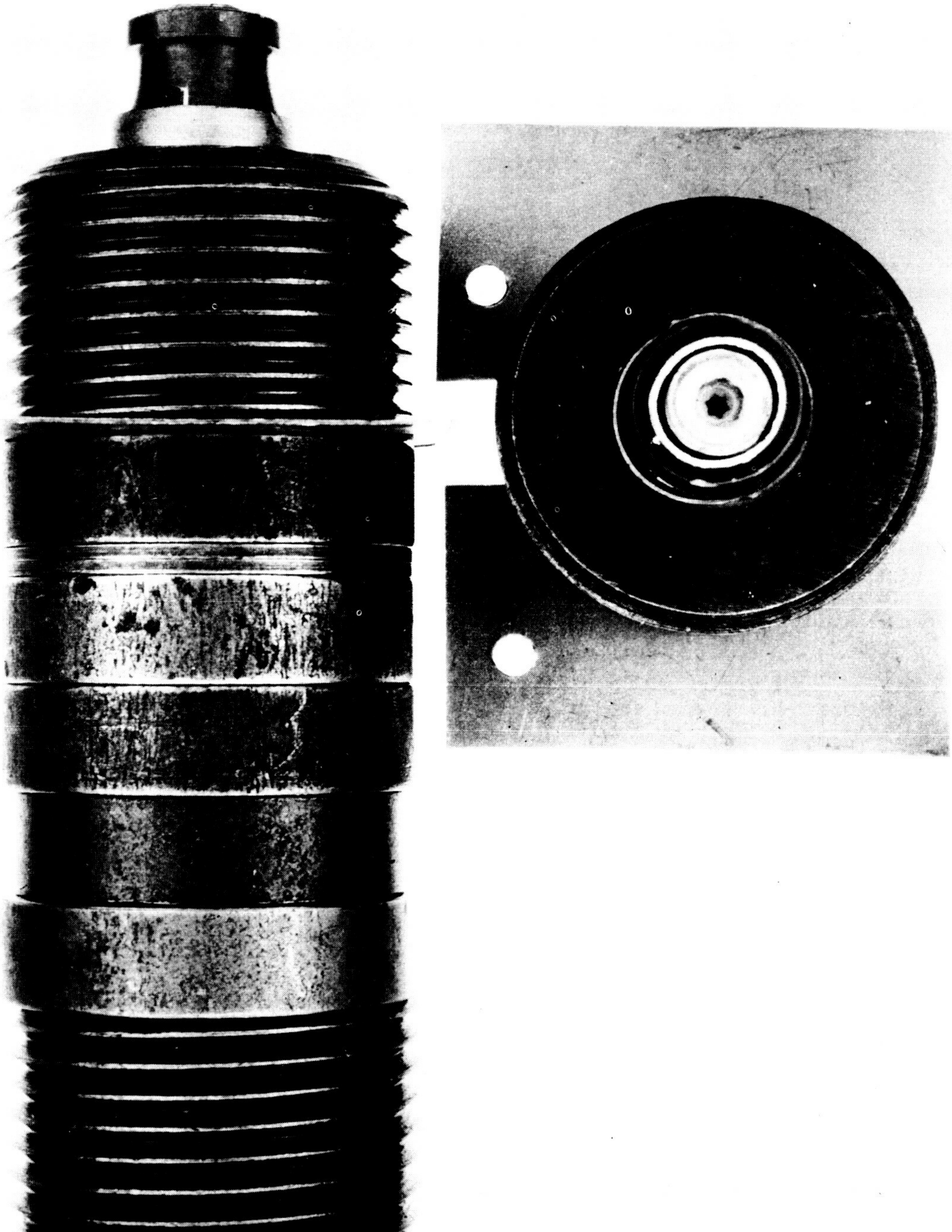


Figure No. 11 Tensile Test Fixture for Point Drive and Jo Bolts load was applied. While the load was being applied, a pull of approximately five pounds was exerted on the shims until they could be moved, at which point the load was recorded and determined as the preload.

d. Stress Calculations

The cross sectional areas used for determining the stress values of threaded fasteners varied depending on the type of fastener tested. The basis for these calculations is that they closely approximate the stress values obtained from smooth specimens fabricated from the same material and heat treatment. The calculation procedures for determining areas used in the test programs were as follows:

1. Cross sectional area

$$a = \pi r^2$$

where: $r = \dfrac{\text{nominal dia}}{2}$

$\pi = 3.1416$

2. Area at Basic Pitch Diameter

$$a = .785398\,(\text{Basic Pitch Dia.})^2$$

where: $.785398 = \dfrac{3.1416}{4}$

Basic Pitch Dia. = From H28 - Screw Thread Standards for Federal Service

3. Tensile Stress Area of External Threads

$$a = \pi \left(\frac{E}{2} - \frac{3H}{16} \right)^2$$

where: π = 3.1416
E = Basic Pitch Dia. (from H-28)
H = Height of Thread to Sharp V

4. Tensile Stress Area of .003 Reduced Pitch Diameter

$$a = \pi\left(\frac{E}{2} - \frac{3H}{16}\right)^2$$

when π = 3.1416
E = Basic Pitch Dia. minus .003 inches
H = Height of Thread to Sharp V

2. Shear

The shear tests were also conducted on the Tinius Olsen Universal Testing Machines at a uniform loading rate of 65,000 psi per minute.

a. Double Shear

The double shear tests were conducted, employing the test fixtures shown in Figures 12, 13, and 14. The test setup is similar to that required in NAS 498 specification except that the bearing surface of the inserts was equal to the diameter of the fastener being tested. The test fixtures were fabricated from Vasco Max 300 (18 per cent nickel maraging steel) for cryogenic shear tests and the nickel base alloy, AF 1753, for elevated temperature tests.

Double shear tests at -423°F of the 3/8 and 1/2 inch diameter fasteners were not completed. Only a limited number of tests were completed before catastrophic failure occurred in the test fixtures. It is believed that design and material selection were the cause of these failures. New fixtures have been redesigned, and will be made from A-286 material.

b. Single or Lap Shear

Single or lap shear tests were conducted on the semi-blind and solid rivets employing a fixture as shown in Figure 15. The fixtures were fabricated from high strength A-286 material (200 ksi) and performed a satisfactory job without distortion at the testing surfaces. Measurements were made of hole diameters intermittently to insure that they were within tolerance prior to each test.

3. Stress Rupture

The stress rupture tests were conducted on Arcweld Stress Rupture Machines. This machine employs a lever arm that has

PD 300 61042

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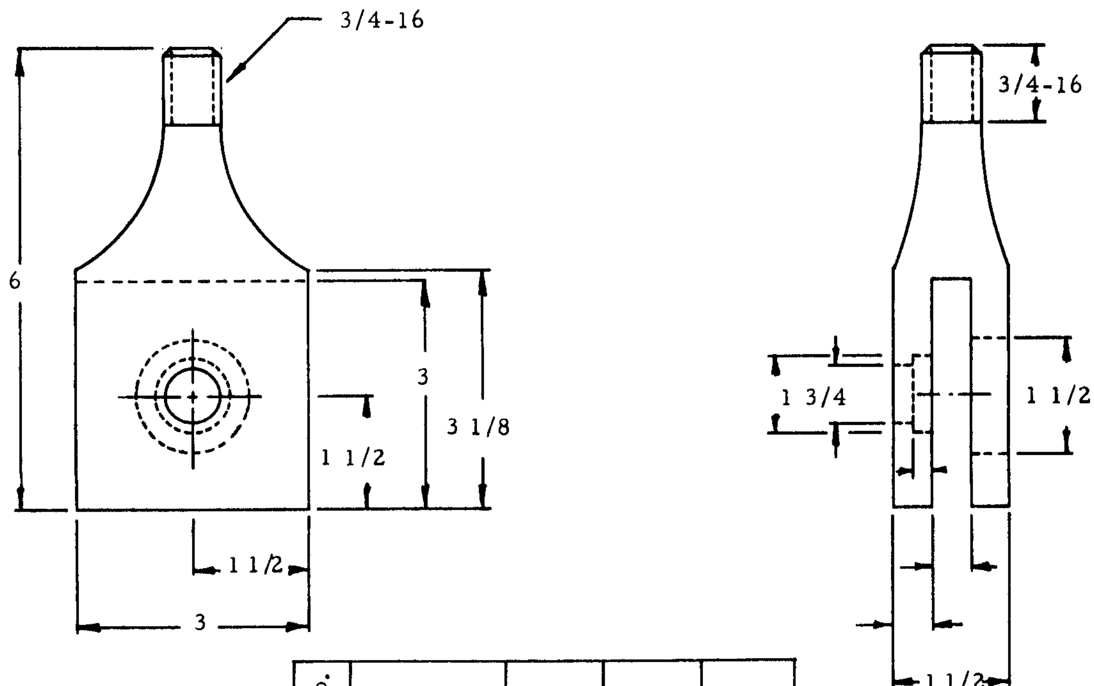

Item No.	Nominal Fastener Diameter	T +.001 -.000	U	V +.001 -.000
1	3/16	.190	.655	.190
2	1/4	.250	.625	.250
3	1/2	.500	.500	.500

DOUBLE SHEAR FIXTURE
EXTERNAL MEMBER

TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH

STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA

DRAWN BY R. Hardiman
DATE 12-2-64

MATERIAL AND HEAT TREAT
AF 1753 Rc 40
Vasco Max 300 - Rc 54

Figure 12

PD • 302 • 61042

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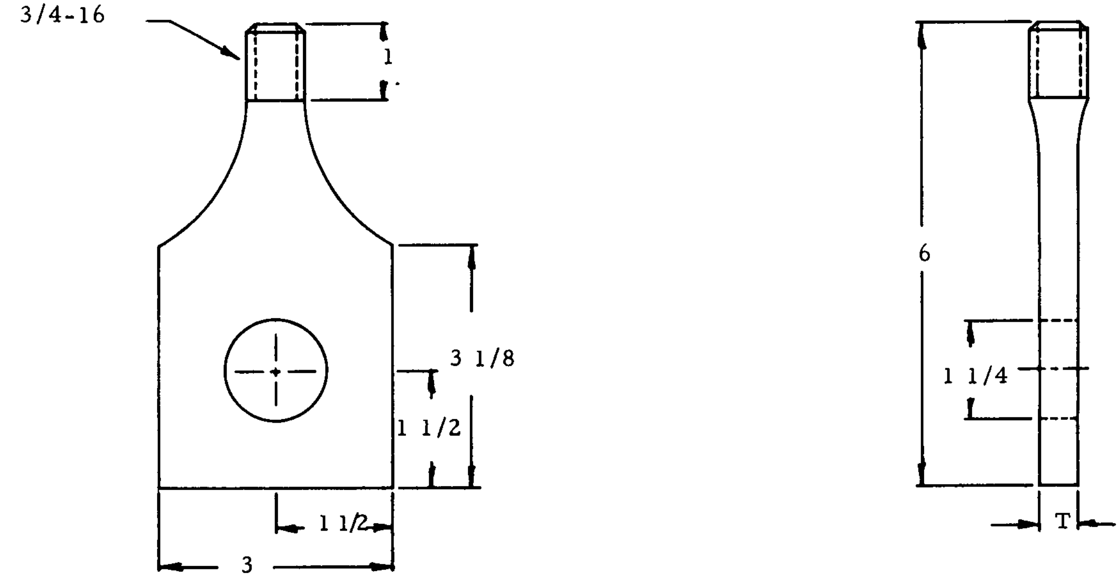


Nominal Fastener Diameter	T +.000 -.001
3/16	.190
1/4	.250
1/2	.500

DOUBLE SHEAR FIXTURE
INTERNAL MEMBER

TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH

STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA

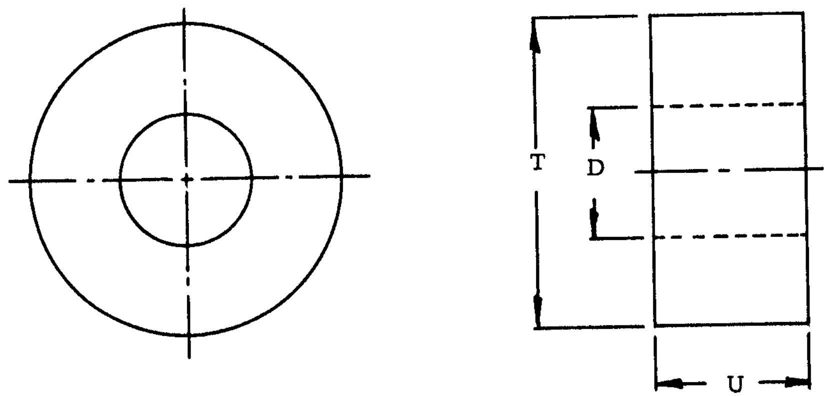
DRAWN BY R. Hardiman
DATE 12-2-64

MATERIAL AND HEAT TREAT
AF 1753 Rc 40
Vasco Max 300 - Rc 54

Figure 13

PD • 301 • 61042

REVISION AND DATE



Item No.	Nominal Fastener Diameter	D Maximum	D Minimum	T +.000 -.001	U +.000 -.001
1	3/16	.1910	.1903	1.00	.190
2	1/4	.2510	.2503	1.00	.250
3	1/2	.5010	.5003	1.00	.500
4	3/16	.1910	.1903	1.25	.190
5	1/4	.2510	.2503	1.25	.250
6	1/2	.5010	.5003	1.25	.500
7	3/16	.1910	.1903	1.50	.190
8	1/4	.2500	.2503	1.50	.250
9	1/2	.5010	.5003	1.50	.500

DOUBLE SHEAR INSERTS

TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH

DRAWN BY R. Hardiman
DATE 12-2-64

STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA

MATERIAL AND HEAT TREAT
AF 1753 Rc-40
Vasco Max 300 - Rc 54

Figure 14

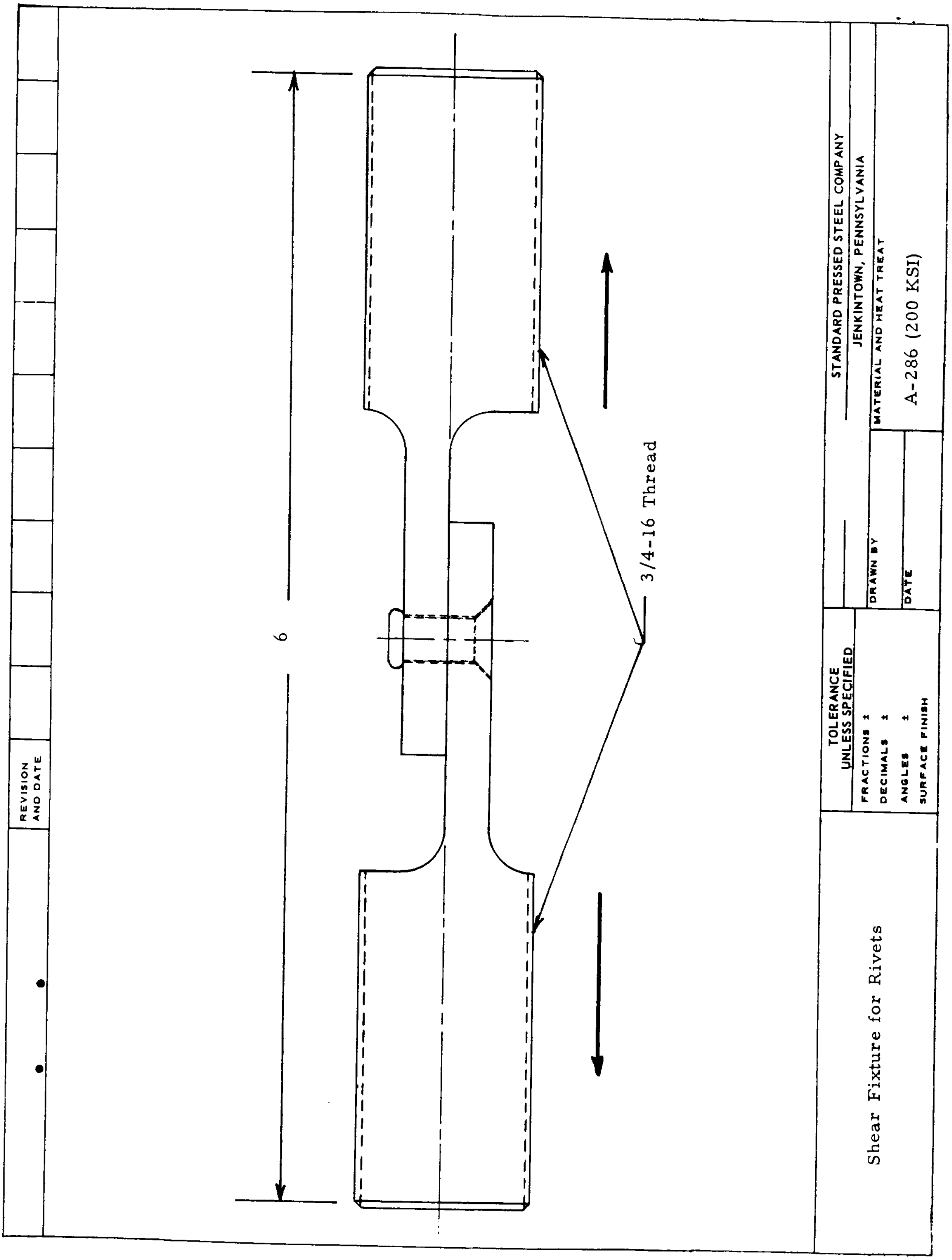

REVISION AND DATE
6
3/4-16 Thread
STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA
MATERIAL AND HEAT TREAT
A-286 (200 KSI)
DRAWN BY
DATE
TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH
Shear Fixture for Rivets

Figure 15

a ratio of 20:1. Load is applied by dead weights which insure a constant load for the duration of the test. The fixtures, shown in Figure 16, are fabricated from super alloys capable of withstanding the test load without deformation at test temperatures of 1600°F and provide uniaxial loading conditions.

4. Stress Relaxation

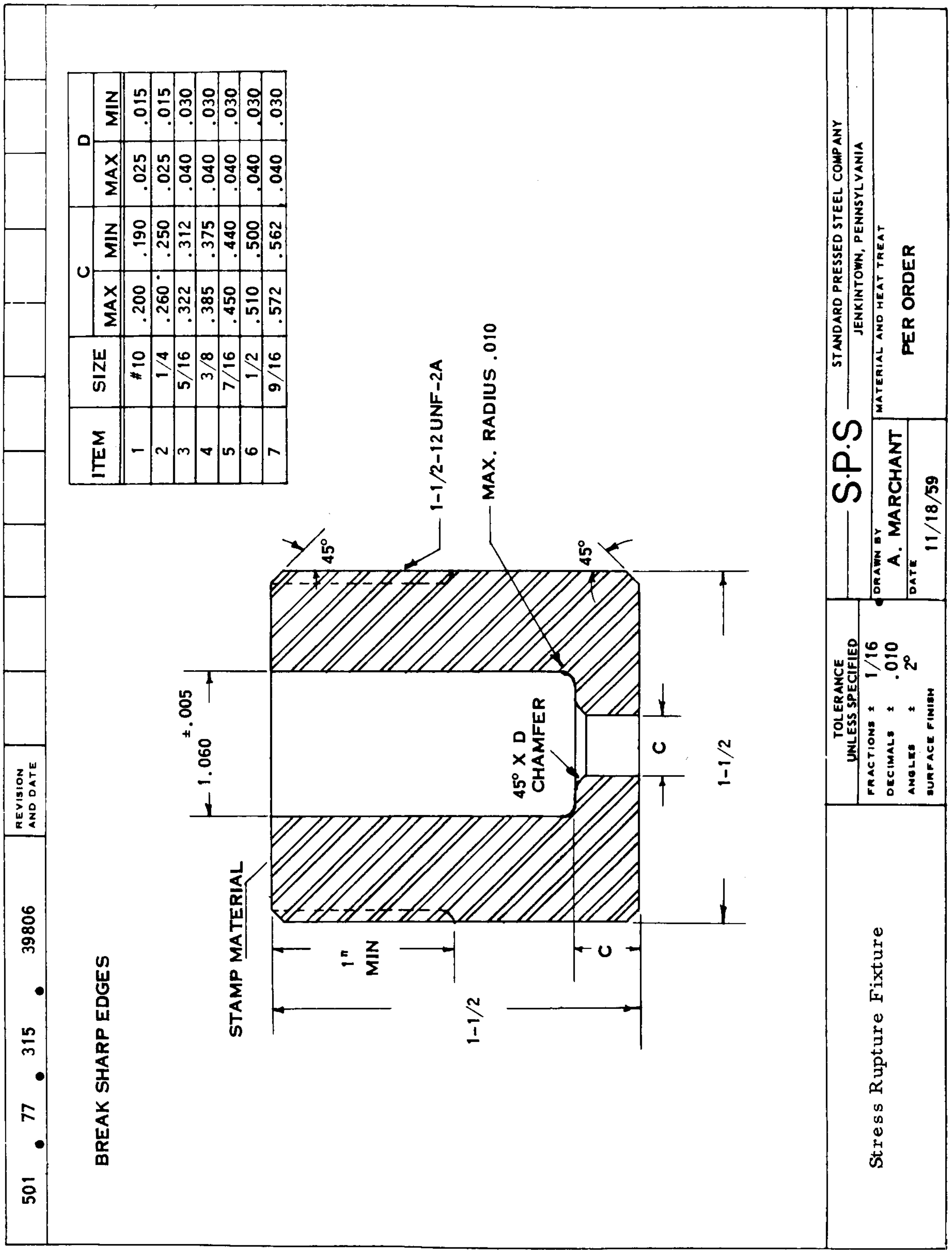
The stress relaxation tests were conducted employing cylinders fabricated from the same material as the test specimens. The only exception to this procedure was the Ti 7Al-12Zr fasteners which were tested with Ti 6Al-4V cylinders. Both materials have about the same coefficient of thermal expansion.

The initial preloads employed were fifty and eighty per cent of the room temperature yield strengths as determined from torque versus induced load tests. The loads closely approximate the actual loads that could be induced in a joint in normal application. Figure 17 shows the mean load as the recommended seating torque which is usually applied with a torquing device that has a tolerance of plus or minus 20 per cent. Initially, a preload of 90 per cent was anticipated but tests employing this load indicated fastener assemblies in some cases exceeded their elastic limit at room temperature. Therefore, the high initial preload was decreased to 80 per cent of the torque versus induced load yield strength. The preloads were converted into the stress the fastener assemblies actually felt at the test temperatures. Figure 18 shows how this was accomplished.

The test procedure to determine the residual stresses after ten and fifty hours employing cylinders was as follows:

Nomenclature

L	-	Load
E	-	Elongation
l_o	-	Initial Bolt Length
l_1	-	Loaded Bolt Length
l_2	-	Exposed, Loaded Bolt Length
l_3	-	Exposed, Unloaded Bolt Length
l_4	-	$l_1 - l_2$
l_5	-	$l_3 - l_o$
l_6	-	$l_4 - l_5$



ITEM	SIZE	C		D	
		MAX	MIN	MAX	MIN
1	#10	.200	.190	.025	.015
2	1/4	.260	.250	.025	.015
3	5/16	.322	.312	.040	.030
4	3/8	.385	.375	.040	.030
5	7/16	.450	.440	.040	.030
6	1/2	.510	.500	.040	.030
7	9/16	.572	.562	.040	.030

Figure 16

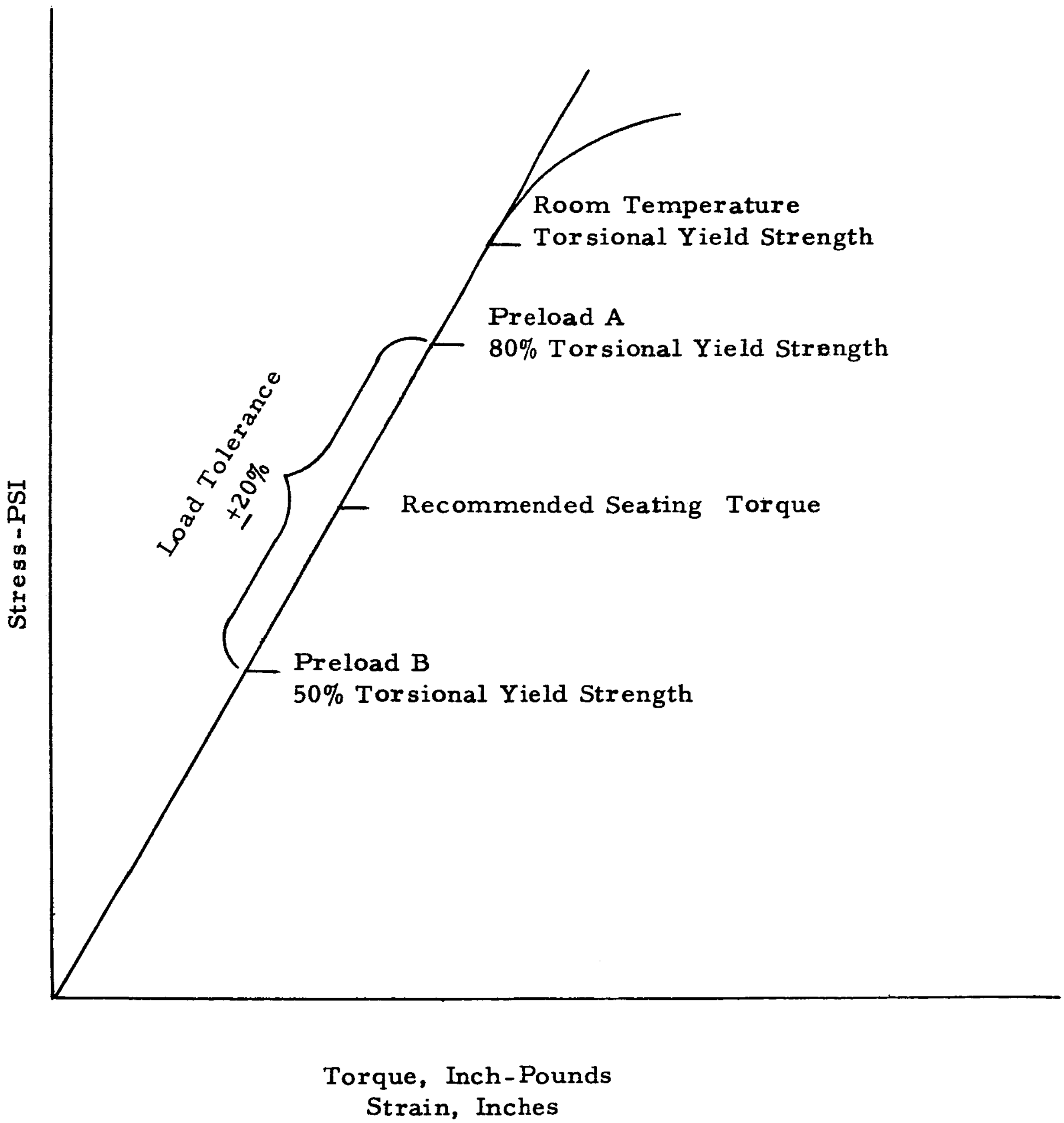


Figure No. 17 Method for Determining Preloads for Relaxation Tests with Cylinders.

Formula

$$\text{Elongation} - \frac{\text{Load X Length}}{\text{Cross sectional area X Mod. of Elasticity}}$$

a. From the torque versus induced load curve the desired 50 per cent and 80 per cent yield strengths were obtained, (L).

b. From the companion fastener tensile load extension curve the elongation (E) required for the desired load (L) was determined.

c. Both ends of the bolts were spot drilled and the length measured (l_o) on a Pratt and Whitney Super Micrometer.

d. The fastener assemblies were loaded in the cylinders to the elongation established in (b).

e. The assemblies were then exposed to their maximum utilization temperature in an electric furnace for the desired period of time.

f. The assemblies were cooled to room temperature and the length was measured while still in the stressed condition (l_2).

g. The assembly was disassembled and the bolt length measured (l_3).

h. Joint relaxation was then calculated (l_6).

i. From the modulus of elasticity data of the fastener material, load extension curves were plotted at the test temperature the fastener assembly was exposed.

j. From (l_6) and the curve in (i), the residual stress at temperature was determined.

Example

Bolt	-	EWB 1615-4-38
Nut	-	FN 1418-428
Size	-	1/4-28
Material	-	Waspaloy (150 ksi)
Test Temperature	-	1400°F
Time	-	10 hours

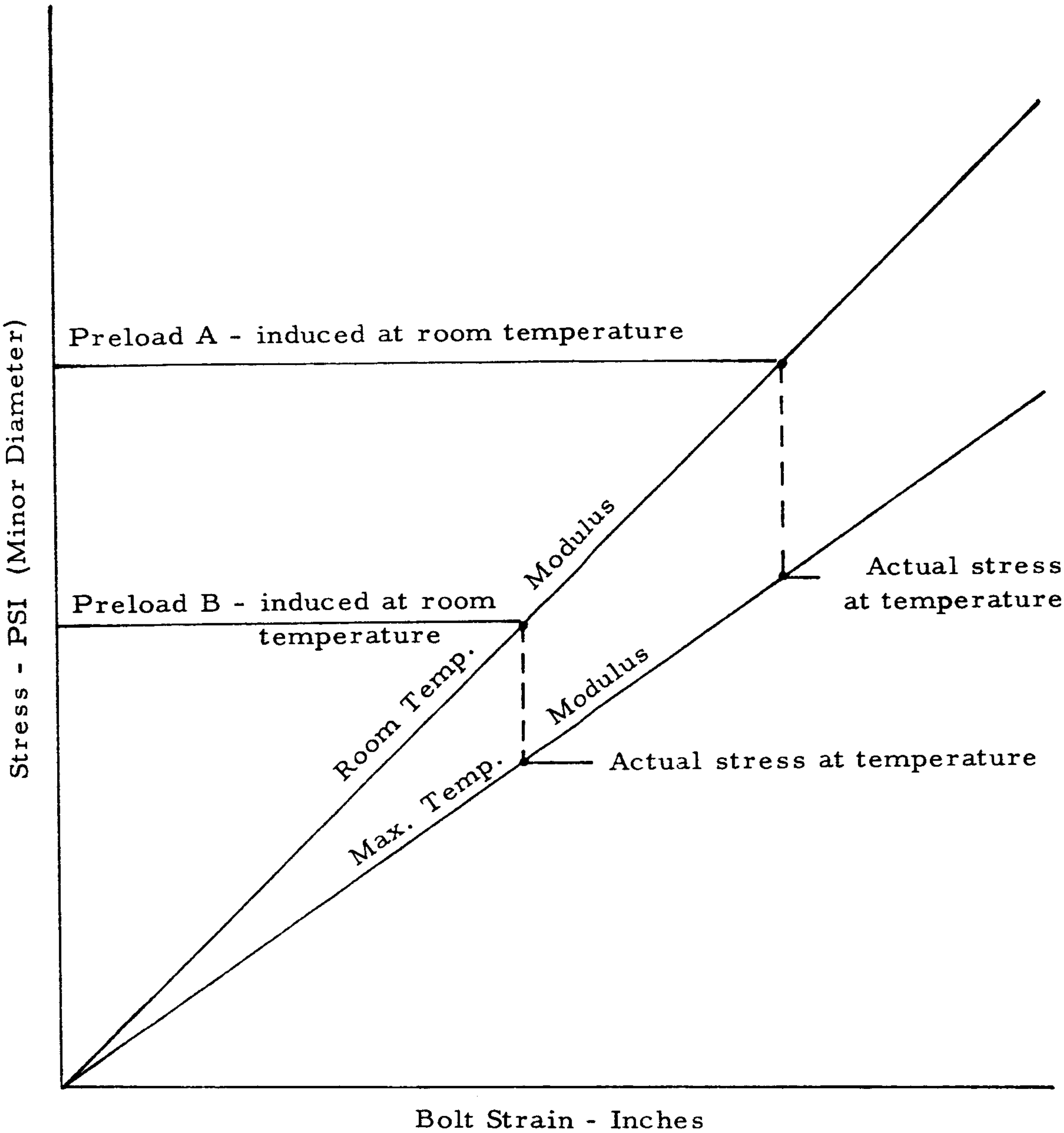


Figure No. 18 Method for Determining Cylinder Relaxation Stress at Maximum Temperature

L - 2,342 pounds
E - .0039 inches
l_o - gauge plus .9045
l_1 - .9084
l_2 - .9078
l_3 - .9051
l_4 - $l_1 - l_o$ = .9084 - .9078 = .0006
l_5 - $l_3 - l_o$ = .9051 - .9045 = .0006
l_6 - $l_4 + l_5$ = .0006 + .0006 = .0012
Residual Elongation = .0039 - .0012 = .0027
From Figure 18 - Residual Load = 1,350 pounds

Calculations for Figure 19

Preload A - 3903 pounds
Shank Area - .049 square inches - shank length = 2.375 inches
Thread Area - .03256 square inches - thread length = .250 inches
Modulus of elasticity at 70 F - 31.9×10^6 psi
Modulus of elasticity at 1400 F - 24.6×10^6 psi

At 70°F with a load of 3903 pounds:

$$\text{Elongation of shank} - \frac{3903 \times 2.375}{.049 \times 31.9 \times 10^6} = .0059 \text{ inches}$$

$$\text{Elongation of thread} - \frac{3903 \times .250}{.03256 \times 31.9 \times 10^6} = .00095 \text{ inches}$$

At 1400°F with a load of 3903 pounds:

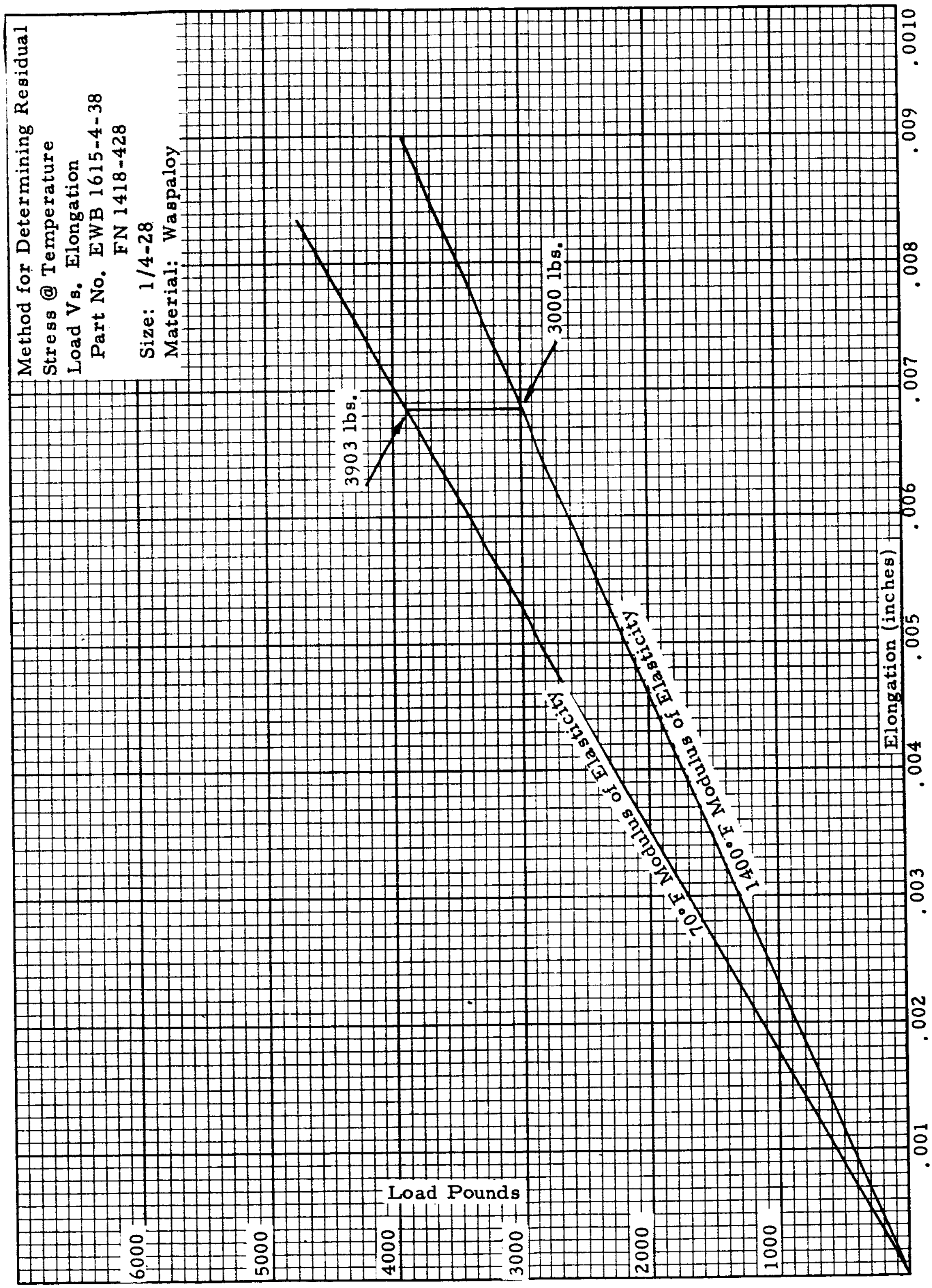
$$\text{Elongation of shank} - \frac{3903 \times 2.375}{.049 \times 24.6 \times 10^6} = .0077 \text{ inches}$$

$$\text{Elongation of thread} - \frac{3903 \times 2.50}{.03256 \times 24.6 \times 10^6} = .0012 \text{ inches}$$

For a load of 3903 pounds

70°F elongation - .0059 + .00095 = .00685 inches
1400°F elongation - .0077 + .0012 = .0089 inches

Initial stress at 1400°F = 3,000 pounds



Method for Determining Residual
Stress @ Temperature
Load Vs. Elongation
Part No. EWB 1615-4-38
FN 1418-428
Size: 1/4-28
Material: Waspaloy
3903 lbs.
3000 lbs.
70°F Modulus of Elasticity
1400°F Modulus of Elasticity
Elongation (inches)
.001
.002
.003
.004
.005
.006
.007
.008
.009
.0010
Load Pounds
1000
2000
3000
4000
5000
6000

Figure 19

The fastener assemblies subjected to the fifty hour relaxation tests were subsequently tested in tension and shear at room temperature to determine the effects of relaxation on the mechanical properties.

5. Nut Reuse and Galling Tendency

Nut reuse and galling tendency were conducted simultaneously. The test procedures employed closely approximate the AMS7250 specification except that various elevated temperatures were used with no lubrication on the nuts. The locknuts assembled on companion bolts were seated in cylinders of the same material at 54 per cent of the rated ultimate strength of the fastener assembly. The loads were determined by elongation employing the Pratt and Whitney super micrometer. The loaded assemblies were cycled five times, using three different cycles as follows:

a. Room temperature to -423°F to room temperature

b. Room temperature

c. Room temperature to maximum utilization temperature to room temperature.

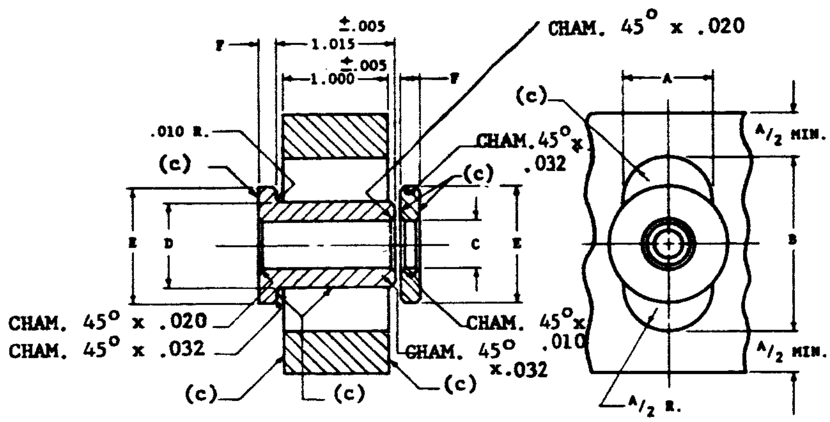
The assemblies were held at -423° F and elevated temperatures for five minutes with breakaway and prevailing torques being recorded after each cycle.

6. Vibration

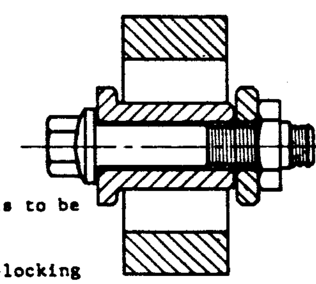
Vibration tests were conducted on a modified Sonntag Fatigue Machine in accordance with ALMA #10 specification. The test fixtures are shown in Figure 20.

The locknuts were seated to twice their maximum locking torque requirements for four applications, at which time the test unit was relubricated, retightened, and placed in the test fixture with five similarly prepared specimens. The vibration tests were conducted at 1750 to 1800 cycles per minute at an amplitude of .450 inches. The tests were run for 30,000 cycles, with intermittent checks every 5,000 cycles after which the nuts were inspected for rotation and cracks. Cracks visible under 10X magnification and/or rotation exceeding 360 degrees constituted a failure.

7. The torque versus induced load tests were run on a North Bar Torque Tension Machine. These tests were run primarily for the determination of torque versus induced load yield strengths to



SIZE	SLOT WIDTH A +.005 −.002	SLOT HEIGHT B ±.002	WASHER AND CYLINDER I.D. C ±.002	CYLINDER O.D. D ±.002	WASHER O.D. E ±.005	WASHER FACE THICKNESS F ±.002
10	.328	1.071	.200	.322	.550	.123
1/4	.500	1.245	.265	.495	.750	.163
5/16	.625	1.370	.328	.620	.875	.163
3/8	.750	1.495	.390	.745	1.000	.163
7/16	.875	1.620	.452	.870	1.200	.188
1/2	1.000	1.745	.515	.990	1.375	.188
9/16	1.125	1.870	.578	1.115	1.550	.213
5/8	1.250	1.995	.640	1.240	1.700	.213



a—Material: Steel, AMS6304

b—Heat Treatment: R_c 40-45.

c—Surface Roughness: On surfaces coded (c) the finish is to be 32 micro inches RHR max.

d—Use: This fixture is used in vibration tests of self-locking nuts. An assembly of the fixtures, bolt and self-locking nut is shown.

REVISION

APPROVAL DATE 4/8/63

CUSTODIAN: TECHNICAL COMMITTEE, AIRCRAFT LOCKNUT MANUFACTURERS ASSN.

PROCUREMENT SPECIFICATION	TITLE FIXTURES-VIBRATION TEST — SELF-LOCKING NUTS	AL-118 SHEET 1 OF 1

Figure 20

be used in conjunction with the relaxation tests.

8. Corrosion Resistance

Corrosion resistance tests were conducted under accelerated salt spray and seacoast environments. The test specimens were installed in space vehicle construction material of 7075-T6 aluminum, 2219-T87 aluminum, annealed Ti 6Al-4V, and annealed 321 stainless steel. The fasteners were not torqued to any specific torque level but were tightened sufficiently to insure contact between the fastener and the space vehicle material. The conditioning of the test specimens and structural material prior to being subjected to the environment tests are shown in Table 15.

a. Accelerated Salt Spray Test

The accelerated salt spray environmental tests were conducted in accordance with Federal Test Method Standard 151, Method 811. The specimens were monitored on a daily basis.

b. Seacoast Environmental Test

Seacoast environmental corrosion tests were conducted outdoors at Long Beach Island, New Jersey on the ocean front. The specimens submitted for this test were situated at a distance of 190 feet from the water's edge. The specimens were set at an angle of 45 degrees with the horizontal plane of the test station fixture and faced east toward the ocean. Figure 21 shows the test stand in relation to the shore line.

The seacoast environmental corrosion tests were monitored on a bi-monthly basis for the first two months, and then monthly for the next four months. Tests will continue for another year.

9. Thermal Cycling

The thermal cycling tests were conducted employing two separate cycles:

a Room temperature to -423°F to room temperature.

b. Room temperature to maximum utilization temperature to room temperature.

The test specimens were seated in cylinders fabricated from the same material as the fastener assemblies being tested. The assemblies were preloaded prior to cycling to a load equivalent to the maximum load employed in fatigue tests of the particular

TABLE 15

SURFACE CONDITIONS OF FASTENER ASSEMBLIES
FOR CORROSION RESISTANCE TESTS

Fastener Material	Structural Metal	Conditions: Fastener Material	Conditions: Structural Metal
Fe base (non cres) H-11 8740 18% Ni Maraging (Vasco Max 300)	7075-Al 2219-Al	Bare	Bare
		Cd plate	Anodized
		Cd plate	Mil-C-5541 plus zinc chromate primer
	321 S/S	Bare	Bare
		Ni plate	Bare
	Ti 6Al-4V	Bare	Bare
		Ni plate	Bare
Ti base 6-4 7-12 1-8-5	7075-Al 2219-Al	Bare	Bare
		Bare	Anodized
		Zinc chromate primer	Mil-C-5541 plus zinc chromate primer
	321 S/S	Bare	Bare
Ni base Waspaloy Inco 718	7075-Al	Bare	Bare
		Cd plate	Anodized
		Cd plate	Mil-C-5541 plus Zinc chromate primer
	321 S/S	Bare	Bare
	Ti 6Al-4V	Bare	Bare
Fe base (cres) A-286 U-212	7075-Al 2219-Al	Bare	Bare
		Cd plate	Anodized
		Cd plate	Mil-C-5541 plus zinc chromate primer
	Ti 6Al-4V	Bare	Bare
Al base 2024 2017	7075-Al 2219-Al	Bare	Bare
		Anodized	Anodized

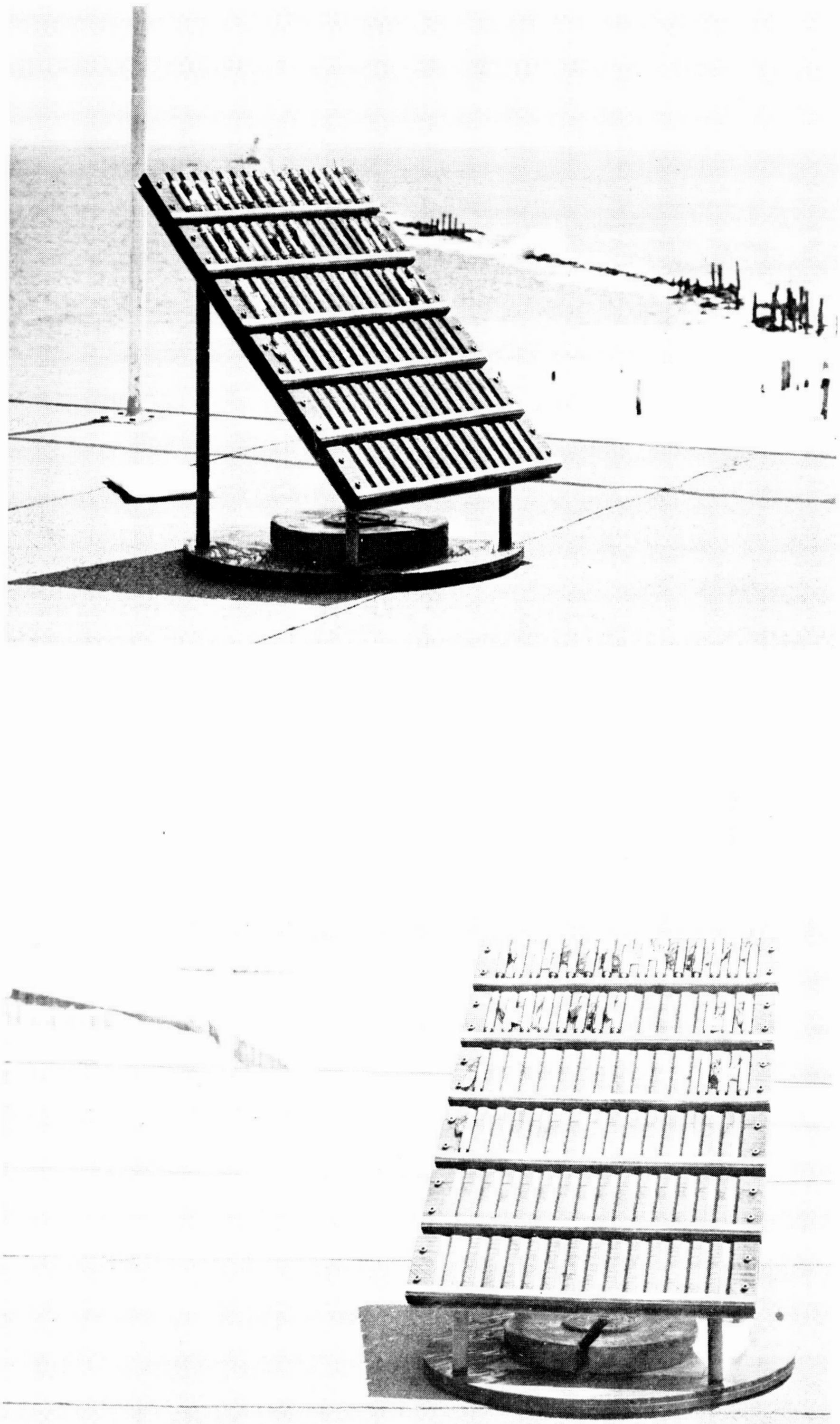


Figure No. 21 Site at Sea Coast of Environmental
Corrosion Resistance Tests

fastener assembly being tested. Where no fatigue loads existed, a preload of 52 per cent of the rated ultimate strength was used.

In addition, loss of preload due to cycling was measured. The method for determining loss in preload followed along the same lines as those outlined for the stress relaxation tests. Test procedure was as follows:

Nomenclature

L	-	Preload
E	-	Elongation
l_o	-	Initial Bolt Length
l_1	-	Loaded Bolt Length
l_2	-	"As Cycled" Loaded Bolt Length
l_3	-	"As Cycled" Unloaded Bolt Length
l_4	-	$l_1 - l_2$
l_5	-	$l_3 - l_o$
l_6	-	$l_4 - l_5$
l_7	-	$E - l_6$

a. Preload (L) obtained from fatigue loads on 52 per cent of rated U. T. S.

b. From fastener assembly load extension curve, the elongation (E) was determined for desired preload (L).

c. Spot drilled both ends of bolts and measured the length (l_o) on Pratt and Whitney super micrometer.

d. Loaded bolts to the elongation (E) determined in (b).

e. Cycled 12 times at desired temperature. Specimens were held five minutes at temperature.

f. Measured length after cycling at room temperature while still in the loaded condition (l_2).

g. Disassembled nut and measured bolt length (l_3).

h. Calculated the loss in preload (l_7).

i. From (l_7) and the load extension curves, the loss in preload after cycling was determined.

Elevated temperature cycling tests were conducted, using fast and slow heating rates on representative classes of fasteners. The maximum applicable temperature for the fast cycle was reached within one minute, employing the infra-red furnace, and the time required to reach maximum temperature for the slow cycle varied depending on the temperature desired. The slow cycle tests were accomplished using resistance wound Marshall furnaces. Figure 22 shows the test setup employed for elevated temperature cycling using the fast rate of approach in conjunction with the infra-red furnace.

Upon completion of cycling tests, the fastener assemblies were tested in tension and shear at room temperature to determine if there was any effect from cycling on the mechanical properties.

10. Cryogenic and Elevated Temperature Tests

a. Cryogenic Temperature Tests

(1) Tensile and Shear

The -423°F tensile and shear tests were conducted employing a cryostat capable of enabling the test specimen to be completely submerged in liquid hydrogen for the duration of the test. All tests were conducted on a 60,000 pound Tinius Olsen Universal Testing Machine that is calibrated once a month to insure accuracies of direct load reading of plus or minus one per cent.

Initially, the test specimens were placed in the cryostat employing special adapters, and the cryostat in turn, was attached to the test adapters of the tensile machine. After being attached to the test adapters, the test specimens were then completely submerged in liquid nitrogen (LN_2) for a minimum period of three minutes, after which the nitrogen was immediately purged out with helium gas and replaced with liquid hydrogen (LH_2). The test specimens were then kept completely submerged in the LH_2 for a period of three minutes before test was initiated. The only deviation from this procedure was for the #10 and 1/4 inch fasteners, which subsequently were held for one minute while immersed in the LH_2 prior to testing.

(2) Cycling Tests

The cycling of test assemblies at -423°F was accomplished, employing the same procedures outlined for tensile and shear except that the test assemblies were kept completely submerged in LH_2 for a period of five minutes. After five minutes, the test assemblies were

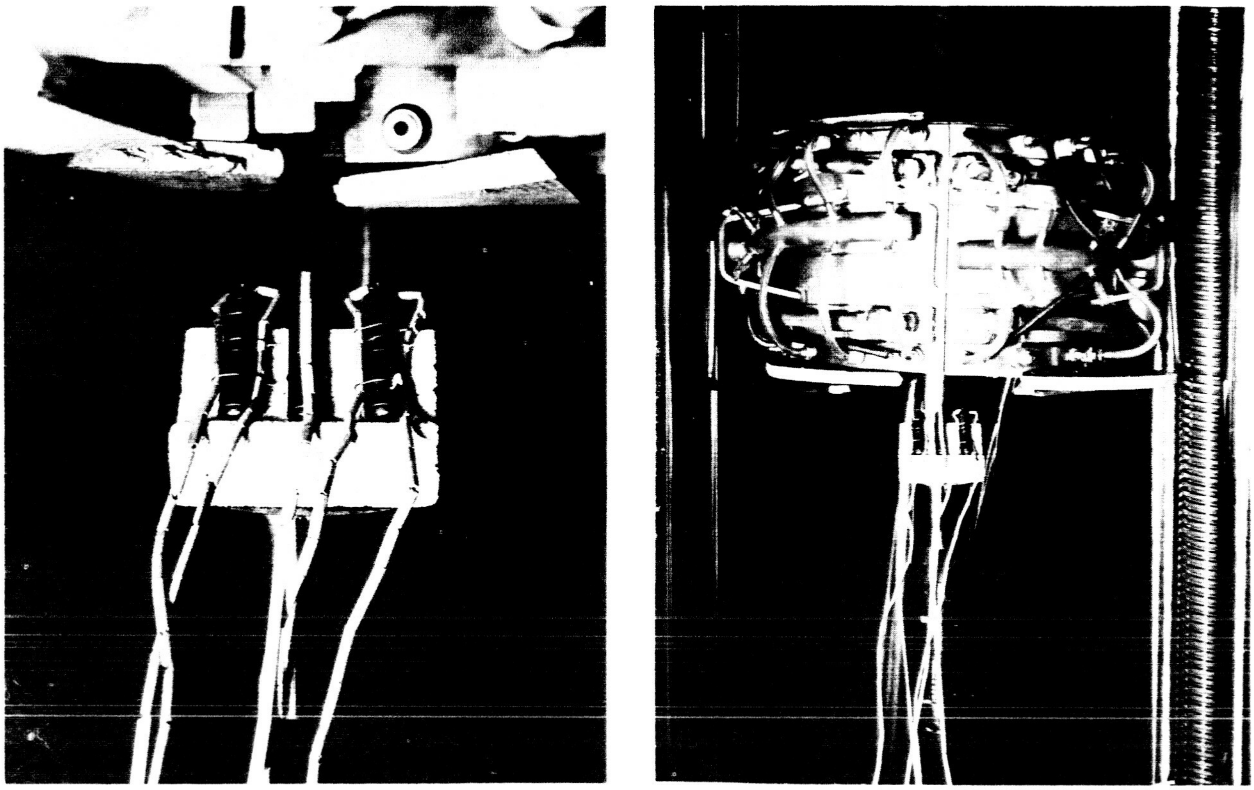


Figure No. 22 Test Set-up for Thermal Cycling at Elevated Temperature with Infra-red Furnace warmed to room temperature and the cycle repeated.

Figure 23 shows the cryostat employed for the cryogenic tests in conjunction with the tensile test station.

b. Elevated Temperature Tests

(1) Tensile

Tensile tests at elevated temperatures were conducted, employing an infra-red furnace shown in Figure 24. The maximum utilization temperature of all fasteners tested was reached within one minute and held for ten minutes before initiating test.

(2) Double Shear

Elevated temperature tests required that the maximum utilization temperature be reached within one minute. In preliminary tests, a thermocouple was placed at the center of the test specimen and one at the end as shown in Figure 25 to determine the variance in temperature between the two points and the time required to reach equality. The results showed that the time required to reach equality for 1/4 inch and 1/2 inch diameter fasteners was four minutes and six minutes respectively.

Subsequently, the #10 and 1/4 inch fasteners were held for 14 minutes at maximum utilization temperature prior to testing, and the 1/2 inch diameters were held for 16 minutes. Figure 26 shows the test fixtures and location of thermocouples in conjunction with the infra-red furnace for elevated temperature double shear tests.

c. Thermal Cycling

The majority of thermal cycling was conducted, employing resistance wound Marshall furnaces, electric furnaces, and a Leeds and Northrup Homo furnace.

d. Stress Rupture

The maximum utilization temperatures for stress rupture tests were obtained with resistance wound Marshall furnaces with maximum operating temperatures to 2000 F.

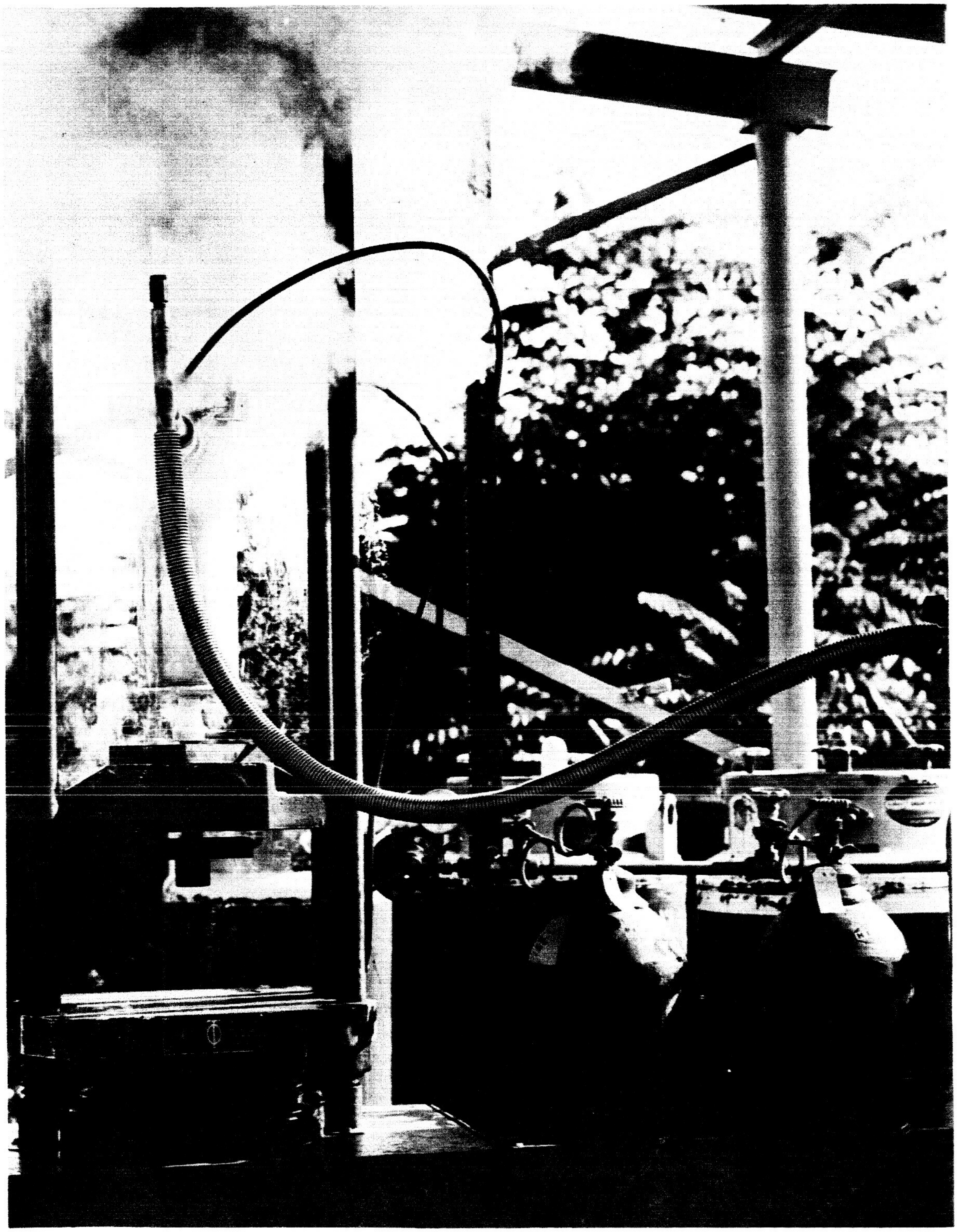


Figure No. 23 Cryogenic Test Station with Cryostat

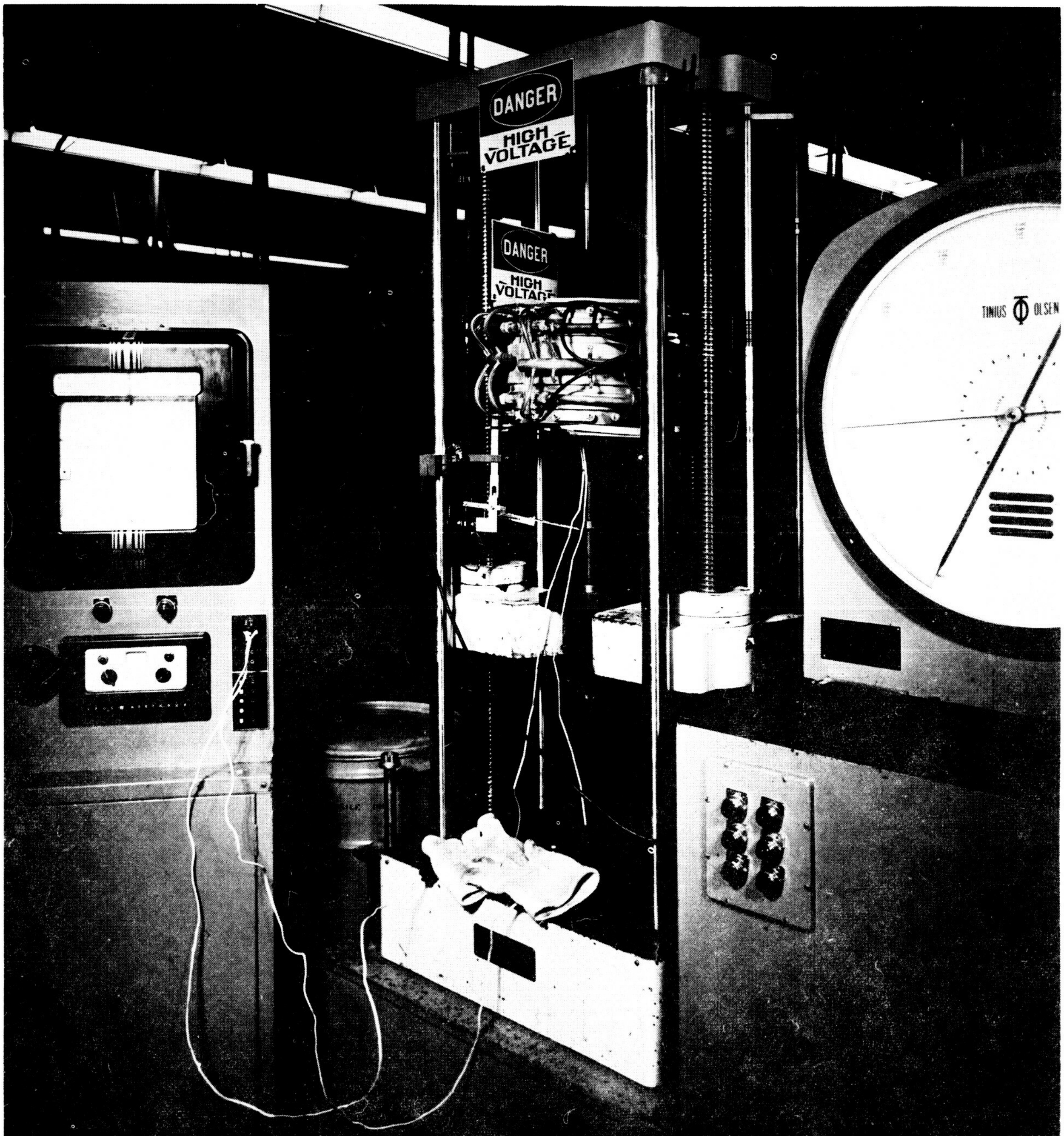


Figure No. 24 Infra-red Furnace in Conjunction with 30,000 Pound Tinius Olsen Tensile Machine

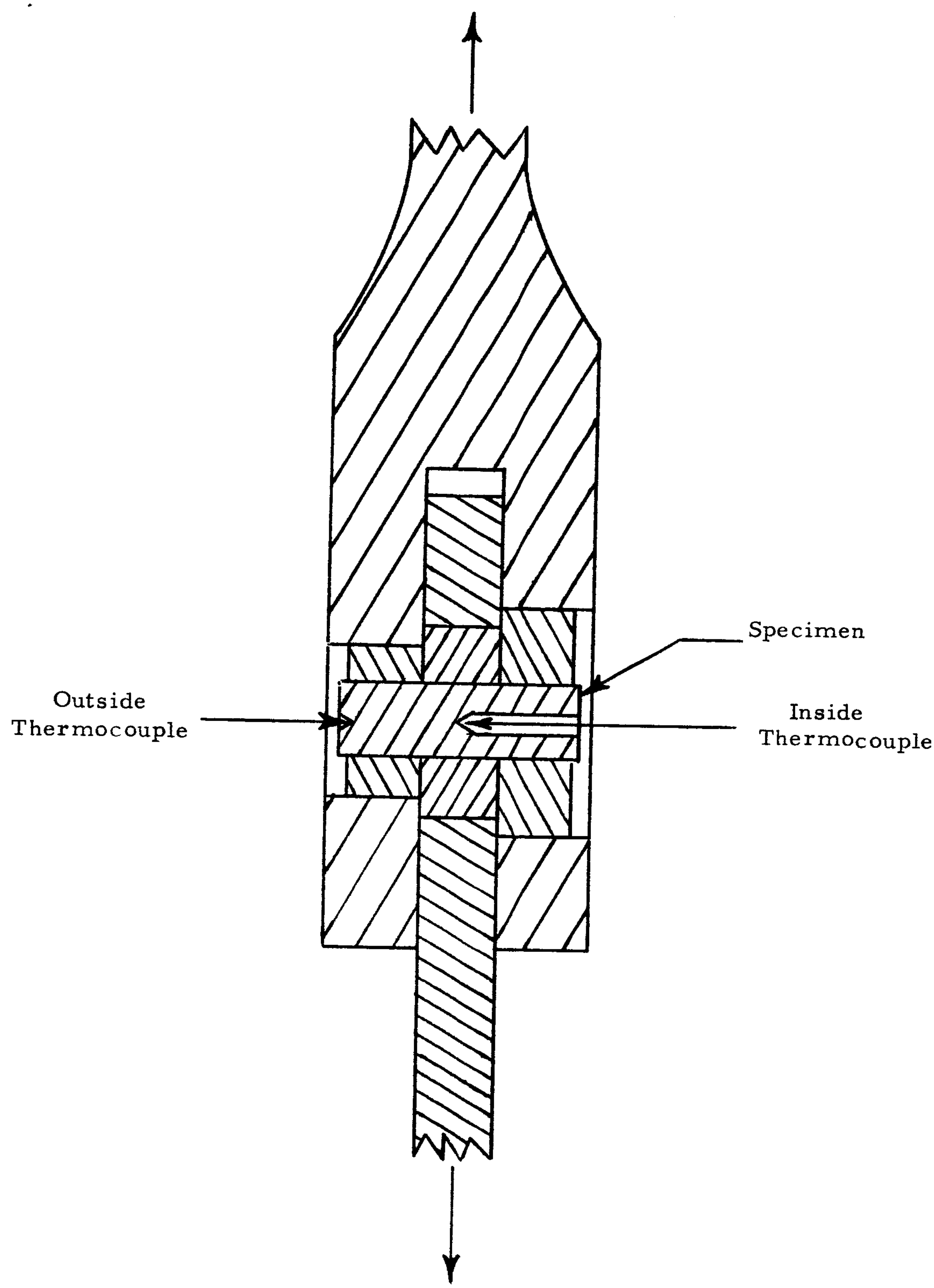


Figure No. 25 Thermocouple Location for Temperature Determination for Elevated Temperature Double Shear Tests.

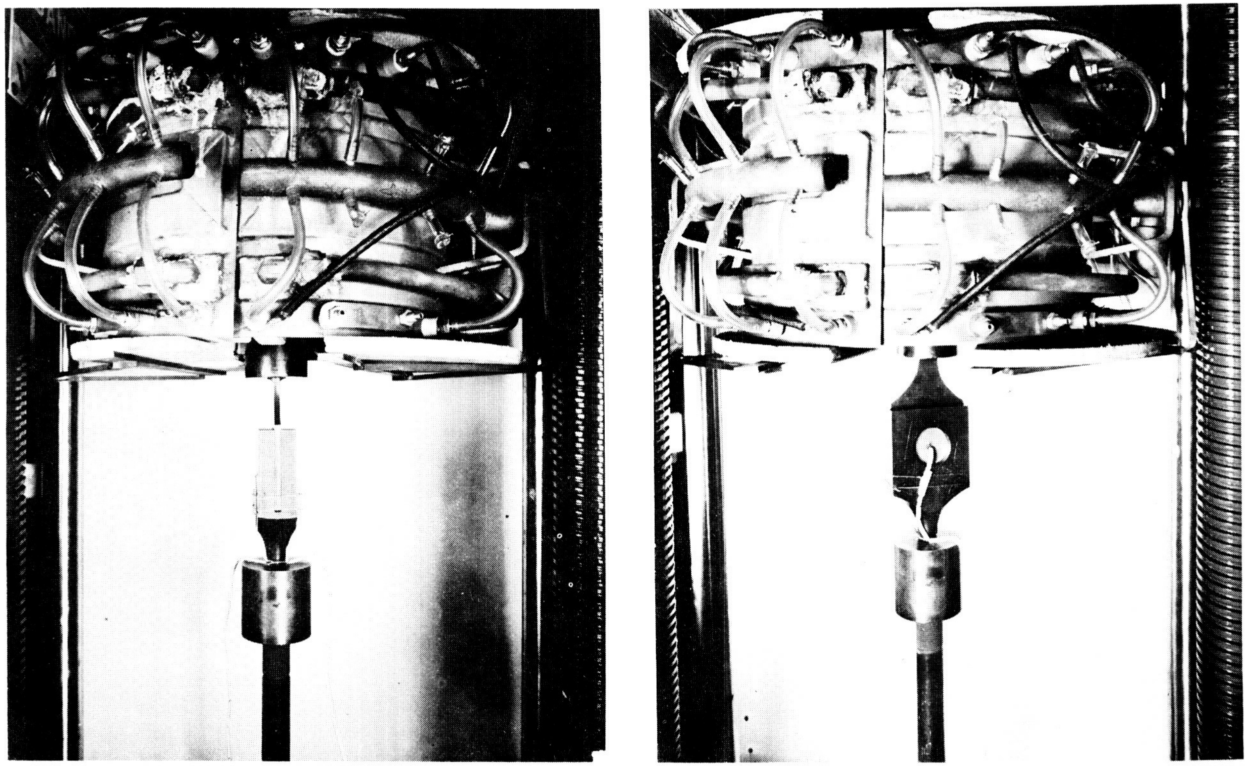


Figure No. 26 Elevated Temperature Double Shear Test Set-up

e. Stress Relaxation

The maximum utilization temperature for the cylinder stress relaxation tests was obtained by employing electric furnaces with maximum operating temperatures to 1800°F.

11. Supplementary Equipment

a. Temperature Measurements

For elevated temperature tests, chromel-alumel thermocouples were used in conjunction with Leeds and Northrop Speedomax L&N temperature controller recorders, capable of maintaining test temperatures within ± 10°F.

E. DISCUSSION OF RESULTS

1. Tension Bolts and Companion Locknuts

All the tension fastener combinations developed the potential strength of the base material at -423°F except for the titanium base fasteners of Ti 6Al-4V and Ti 7Al-12Zr. The data for the titanium fasteners show a significant decrease in the fastener strength at -423°F. However, both alloys exhibited the highest strength to density ratio of the fastener materials tested.

The fastener combination of EWB 22 nuts and 220 ksi H-11 bolts attained full tensile strength at -423°F while the FN 922 nuts failed 30 per cent below room temperature strength. The higher strengths with the EWB 22 nut were attributed to the increased mass employed in the design of this nut.

Size appears to have an effect on the tensile properties at -423°F. The 1/2 inch diameter fasteners and .357 inch specimens showed a drop-off in strength in comparison to the #10 and 1/4 inch fasteners and .113 specimens.

Thermal cycling at both temperature extremes did not have an effect on the mechanical properties of the fastener combinations. Loss in preload was recorded for fastener combinations after cycling at elevated temperatures which may be attributed to the effects of relaxation. Table 16 is a compilation of the results illustrating the loss in preload from cycling to elevated temperatures. Figures 27 and 28 depict microstructures of typical fasteners subjected to thermal cycling to low and elevated temperatures.

TABLE 16

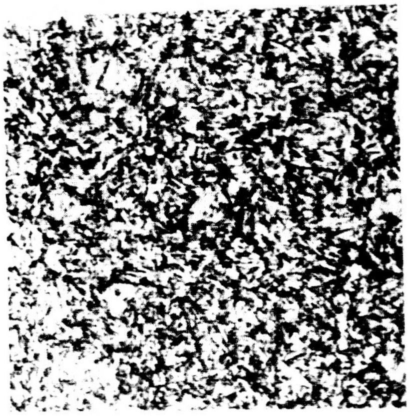
PRELOAD DETERMINATION BEFORE AND AFTER CYCLING

Part No.	Material	Cycled 12 Times at °F	Type of Cycle	Initial Preload Pounds	Initial Preload PSI	Preload After Cycling Pounds	Preload After Cycling PSI	Loss in Preload Pounds	Loss in Preload PSI
EWB1615-1032	Wasp.	+1400	Fast	1600	83,000 (1)	1000	51,900	600	31,100
EWB1615-1032	Wasp.	+1400	Fast	1600	83,000 (1)	980	50,900	620	32,100
EWB1615-1032	Wasp.	+1400	Fast	1600	83,000 (1)	940	48,800	660	34,200
EWB1615-1032	Wasp.	+1400	Slow	1600	83,000 (1)	1000	51,900	600	31,100
EWB1615-1032	Wasp.	+1400	Slow	1600	83,000 (1)	1030	53,500	570	29,500
EWB1615-1032	Wasp.	+1400	Slow	1600	83,000 (1)	1030	53,500	570	29,500
NAS673-36	Ti 6-4	+400	Fast	1660	83,000 (2)	1600	80,000	60	3,000
NAS673-36	Ti 6-4	+400	Fast	1660	83,000 (2)	1600	80,000	60	3,000
NAS673-36	Ti 6-4	+400	Fast	1660	83,000 (2)	1530	76,500	130	6,500
NAS673-36	Ti 6-4	+400	Slow	1660	83,000 (2)	1600	80,000	60	3,000
NAS673-36	Ti 6-4	+400	Slow	1660	83,000 (2)	1530	76,500	130	6,500
NAS673-36	Ti 6-4	+400	Slow	1600	83,000 (2)	1600	80,000	60	3,000
VS2502-3-40	A-286	1200	Fast	2080	104,000 (2)	1190	59,500	890	44,500
VS2502-3-40	A-286	1200	Fast	2080	104,000 (2)	1440	72,000	640	32,000
VS2502-3-40	A-286	1200	Fast	2080	104,000 (2)	1330	66,500	750	37,500
VS2502-3-40	A-286	1200	Fast	2080	104,000 (2)	810	40,500	1270	63,500
VS2502-3-40	A-286	1200	Fast	2080	104,000 (2)	1190	59,500	890	44,500
VS2502-3-40	A-286	1200	Fast	2080	104,000 (2)	1250	62,500	830	41,500
VS2502-3-40	A-286	1200	Slow	2080	104,000 (2)	1190	59,500	890	44,500
VS2502-3-40	A-286	1200	Slow	2080	104,000 (2)	1140	57,000	940	47,000
VS2502-3-40	A-286	1200	Slow	2080	104,000 (2)	1530	76,500	550	27,500
VS2502-3-40	A-286	1200	Slow	2080	104,000 (2)	1030	51,500	1050	52,500
VS2502-3-40	A-286	1200	Slow	2080	104,000 (2)	1330	66,500	750	37,500
EWBTM9-34	H-11	900	Fast	2500	115,000 (3)	1720	79,300	780	35,900
EWBTM9-34	H-11	900	Fast	2500	115,000 (3)	1930	88,900	570	26,300
EWBTM9-34	H-11	900	Fast	2500	115,000 (3)	1630	75,100	870	40,100
EWBTM9-34	H-11	900	Slow	2500	115,000 (3)	1820	83,900	680	31,300
EWBTM9-34	H-11	900	Slow	2500	115,000 (3)	1630	75,100	870	40,100
EWBTM9-34	H-11	900	Slow	2500	115,000 (3)	1720	79,300	780	35,900

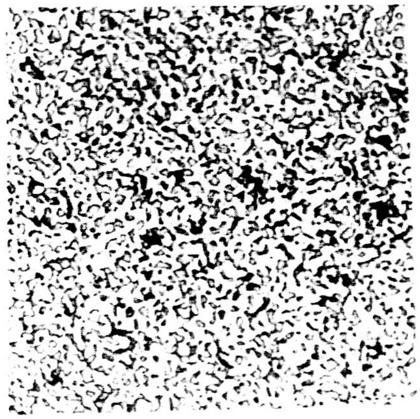
(1) Stress calculated at tensile stress area (.003 red. pitch dia.) of .01925 square inches.
(2) Stress calculated at tensile stress area of .01999 square inches.
(3) Stress calculated at basic pitch diameter of .0217 square inches.

AISI H-11 (220 ksi)
Mag. X 500
Etch - 4% Nital

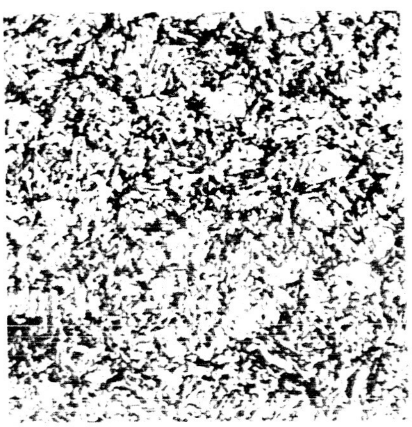
Ti 6Al-4V (160 ksi)
Mag. X 500
Etch - HF, HNO_3 & H_2O



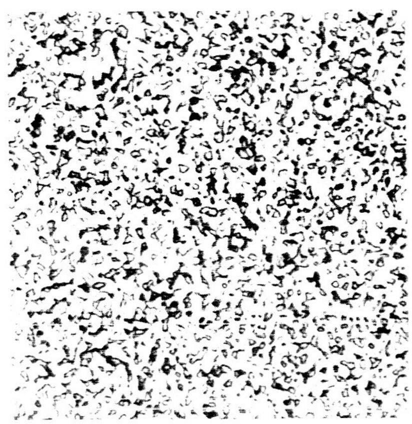
As Cycled @ 900° F



As Cycled @ 400° F



As Rec'd



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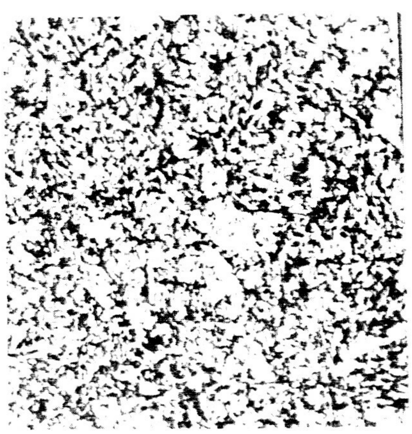
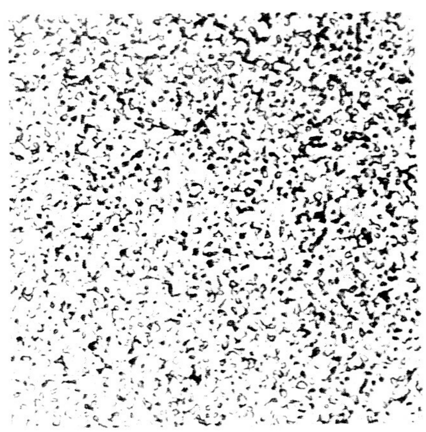


As Cycled @-423° F



As Cycled @-423° F

Figure No. 27 Photomicrostructure of "As Cycled" and "As Received" H-11 and Ti 6Al-4V Fastener Materials

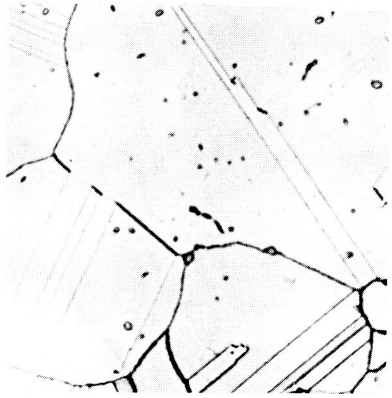
A-286 (200 ksi)
Mag. X 500
Etch - HCL, HNO_3
HAC & H_2O

As Cycled @ 1200°F

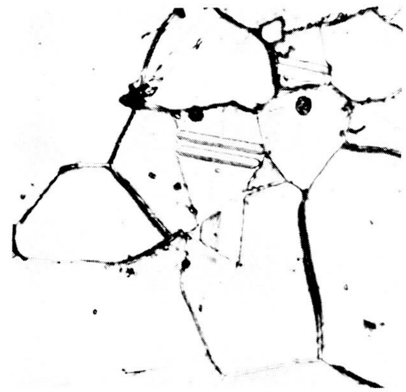
As Rec'd

As Cycled @-423°F

Waspaloy (150 ksi)
Mag. X 500
Etch - Kallings
Reagent



As Cycled @ 1400°F



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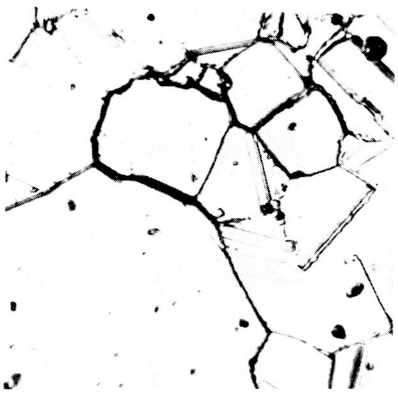


As Cycled @-423°F

Figure No. 28 Photomicrostructure of "As Cycled" and "As Received" A-286 and Waspaloy Fastener Materials

The 50 hours relaxation tests at maximum temperatures did not have an effect on the mechanical properties of fastener combinations except in the case of Waspaloy and A-286 fasteners. The additional aging resulting from response to test temperature during relaxation tests caused a change in the basic material hardness which changed the bolt strength. For A-286 fasteners overaging occurred, resulting in lower strength; and for Waspaloy fasteners, further aging increased the strength.

The shear to ultimate strength ratio at -423°F of H-11 (220KSI) material was slightly below the room temperature ratio. The data shows an inconsistency at -423°F for tensile tests but all values were above room temperature strengths. However, the material showed a significant loss in ductility which in some cases was non-existent at -423°F.

Test data on fasteners fabricated from Waspaloy alloy indicate that this material is notch ductile over the entire temperature range of -423°F to 1400°F. The material ductility was the same at -423°F and room temperature with a percentage of elongation on the order of 14 to 20 per cent. Waspaloy fasteners show excellent properties for space vehicle applications.

The titanium alloys of Ti 7Al-12Zr and Ti 6Al-4V could be considered for cryogenic applications in a limited capacity where ductility is not a prime concern. Tensile and double shear strength increased significantly at -423°F but fastener strength was markedly lower than material strength, and shear to ultimate strength ratio was significantly lower than room temperature ratio. The ratio was .48 at -423° F and .62 at room temperature. It appears that these titanium alloys may be notch sensitive at -423° F as evidenced by the lower fastener strength with no indications of yielding.

Recent evaluation by the Aerojet-General Corporation of the ELI grade Ti 6Al-4V, DMIC report of October 9, 1964, shows it to have good ductility and notched to unnotched tensile ratios at -423°F. Notched to unnotched ratios were above unity at -423°F for specimens with a stress concentration factor of K_t6. This would indicate that the ELI grade of 6-4 titanium and possibly 7-12 titanium have better potential cryogenic fastener application than the standard materials and would warrant further investigation.

The test data on the high strength A-286 material and fasteners show them to possess excellent properties for fastener applications over the entire temperature range of -423°F to 1200°F. A-286 was the only alloy evaluated in Phase II that showed increased ductility at -423°F. In addition, thread strength exceeded the actual material strength at all temperature levels with definite indications that the material was notch ductile.

The amount of cold reduction induced during the fabrication of the A-286 fasteners is unknown but room temperature material strength indicated that is is probably between 35 and 50 per cent.

Nut galling and seizure was prevalent for the silver plated Waspaloy locknuts for the application torque tests at 1600°F. The test temperature was lowered to 1400°F, at which temperature there was no indications of galling and seizure except for the 1/4 inch nuts that failed after three applications. It appears that the maximum utilization temperature for Waspaloy fasteners is 1400°F with limited applications at 1600°F.

The locking characteristics of locknuts were not affected after exposures to LH_2 and elevated temperatures in the stressed condition. The #10 and 1/4 inch bolts of A-286 failed after one application after exposure at 1200°F. Apparently the induced load of 54 per cent of the rated ultimate strength was too high for these fastener combinations, and the exposure to 1200°F temperature reduced the beneficial effects of cold reduction. Catastrophic failures did not occur with the 1/2 inch diameter bolts.

2. Shear Bolts and Companion Locknuts

The shear properties of Ti 6Al-4V shear bolts were the same as those previously mentioned for tension bolts fabricated from the same material. The companion nut of AISI 4027 material used in conjunction with the 6-4 Ti bolt would not be feasible for cryogenic applications. Brittle failure of the nuts occurred in tensile tests at -423°F.

The shear bolts of H-11 alloy heat treated to a strength level of 260 ksi do not warrant consideration for -423°F application. It appears that this material becomes brittle at -423°F as evidenced by shear results below those at room temperature. Further evidence of this material's brittleness at -423°F was derived from the tensile results of specimens which were below room temperature properties and having little or no ductility.

It should be noted that the double shear tests at -423°F of the 3/8 and 1/2 inch diameter fasteners were not completed. Catastrophic failure was prevalent for the Vasco Max 300 shear fixtures. It is concluded that design and material selection were the cause of these failures. New fixtures have been redesigned and are being made from A-286 material. Shear tests at -423°F of the 3/8 and 1/2 inch diameter fasteners will be resumed upon completion of the test fixtures.

3. Point Drive Bolts and Twist-Off Nuts

The shear strength of all point drive bolts increased significantly at -423°F. Tensile tests at -423°F produced head failures for the 3/8 inch diameter 6-4 Ti and 8740 bolts in some cases below the room temperature strength which was attributed to head design.

The 2024 aluminum twist-off nuts tested with cadmium plated 8740 bolts failed the ALMA #10 vibration test in less than 20,000 cycles. The test was rerun with the same results. The same type of nuts tested with 6-4 titanium bolts did not fail after 30,000 cycles. This test is a severe vibration test and is not called out in the specification requirements of this part.

4. Jo Bolts

Jo Bolts fabricated from AISI 4130 alloy do not appear feasible for cryogenic application as evidenced by the double shear tests at -423°F. The data shows the shear strength in one test to be below room temperature shear strength. On the other hand, Jo Bolts fabricated from A-286 show excellent properties for cryogenic application down to -423° F. The data show a 75 per cent increase in shear strength above room temperature shear strength.

It should be noted that the preload and ultimate strength of A-286 Jo Bolts, after cycling and relaxation tests at 1200°F, increased slightly. It is theorized that the cold work induced by the swaging operation in conjunction with the test temperature would precipitate an increase in strength with a resultant increase in preload.

5. Rivets

The data show that the shear strength of all rivets tested increased significantly at -423°F. Solid rivets fabricated from commercially pure titanium had a tensile strength below room temperature strength. However, since rivets are designed for shear application, all the rivets tested in this program appear feasible for cryogenic application down to -423° F temperature.

6. Environmental Corrosion Tests

A determined effort was made to correlate the results of seacoast environmental tests with those obtained under accelerated salt spray atmospheres. Although a definite correlation could not be ascertained, a pattern did exist wherein corrosion, as a result of seacoast environment, was also exhibited in the salt spray tests in a much shorter period of time. However, in cases where stress corrosion was believed to have occurred at the seacoast, similar results did not occur in salt spray. As a result, the corrosion resistance properties of a fastener assembly could probably be determined employing the accelerated salt spray tests; however, the determination of susceptibility to stress corrosion should be conducted under operating conditions such as those experienced at the seaside location.

a. AISI H-11 Fasteners

(1) 2219 and 7075 Aluminum Cylinders

Cadmium plated H-11 fasteners in cylinders of 2219 and 7075 aluminum with the chemical conversion coating per MIL-C-5541 and dipped in a zinc chromate primer ($ZnCr_2O_3$) showed good resistance to corrosion in both atmospheres. There was no indication of fastener or cylinder corrosion after four months.

The same type of aluminum cylinders in the anodized condition showed evidence of corrosion after nine days in salt spray and ten weeks at the seashore.

(2) 321 S/S and Ti 6Al-4V Cylinders

Nickel plate gave very little protection to H-11 fasteners against seacoast and salt spray atmospheres. Nickel plated H-11 fasteners, installed in cylinders of 321 stainless steel, and 6-4 titanium cylinders, showed indications of red rust after one day in salt spray and two weeks at the shore.

b. Waspaloy Fasteners

(1) 2219 and 7075 Aluminum Cylinders

There appears to be a galvanic reaction between cadmium plated Waspaloy and 2219 aluminum. Anodized and alodined 2219 aluminum cylinders showed indications of corrosion at the bearing surface after seven days in salt spray and six weeks at the seacoast.

On the other hand, cadmium plated Waspaloy fasteners in conjunction with treated 7075 aluminum cylinders exhibited good resistance to corrosion in both atmospheres.

(2) 321 Stainless Steel Cylinders

A galvanic reaction was noted between unplated Waspaloy and bare 321 stainless steel under seacoast environments. The 321 stainless steel showed indication of red rust after ten weeks. This was not evident in the accelerated salt spray tests. This is the one exception which does not follow the pattern previously mentioned.

(3) Ti 6Al-4V Cylinders

Unplated Waspaloy fasteners installed in cylinders of bare 6-4 titanium showed excellent resistance to corrosion under both atmospheric conditions.

c. Ti 7Al-12Zr Fasteners

(1) 2219 and 7075 Aluminum Cylinders

Cylinders of 2219 and 7075 aluminum with the chemical conversion coating and zinc chromate primer showed good resistance to corrosion under both atmospheric conditions. However, the same type aluminum cylinders, bare and in the anodized condition, indicate that a galvanic reaction is set up between them and 7-12 titanium fasteners in both atmospheres. Aluminum hydroxide gelatinous $Al(OH)_3$ was noticed at the assembly bearing surface after one day in salt spray and two weeks at the shore location.

(2) 321 Stainless Steel Cylinders

The corrosion resistant properties of 7-12 titanium in conjunction with 321 stainless appears fairly good, but a slight reaction does occur as evidenced by indications of red rust at the bearing surface of the 321 stainless steel cylinders after 4 days in salt spray and 6 weeks at the shore site.

d. Ti 6 Al-4V Fasteners

(1) 7075 Aluminum Cylinders

Ti 6Al-4V fasteners installed in 7075 aluminum cylinders with a chemical conversion coating and dipped in $ZnCr_2O_3$ showed good resistance to corrosion. No indications of corrosion were evident after 4 months at both environments. However, anodized aluminum showed indications of corrosion after 6 days in salt spray and 8 weeks at the shore. Corrosion resistance was slightly better with 6-4 titanium than with 7-12 titanium.

(2) 321 Stainless Steel

The corrosion resistance of 321 stainless steel in conjunction with bare 6-4 titanium fasteners was good but a slight reaction was noted after 3 weeks in salt spray. Indications of red rust were present at the bearing surface of the 321 stainless steel cylinder. It took 12 weeks under seacoast environment before indications were noted.

e. A-286 Fasteners

(1) 7075 Aluminum Cylinders

The best protection afforded plated and unplated A-286 in conjunction with aluminum structural material was with the chemical conversion coating and $Zn Cr_2 O_3$. However, the aluminum showed signs of corrosion after 6 days in salt spray and 8 weeks at the shore in conjunction with cadmium plated A-286, but no corrosion was noted with unplated semi-blind rivets after 4 months.

Anodized aluminum cylinders used in conjunction with A-286 fasteners showed poor resistance to corrosion and in the case of the semi-blind rivet, it appears that the 7075 aluminum material may be susceptible to stress corrosion under seacoast environments. The specimen shown in Figure 29 failed after 4 weeks under the seacoast environment.

It should be noted that a galvanic reaction appears to occur between silver plated A-286 and titanium tension bolts. Red rust was noted on the nuts after one day in salt spray and 2 weeks at the shore location.

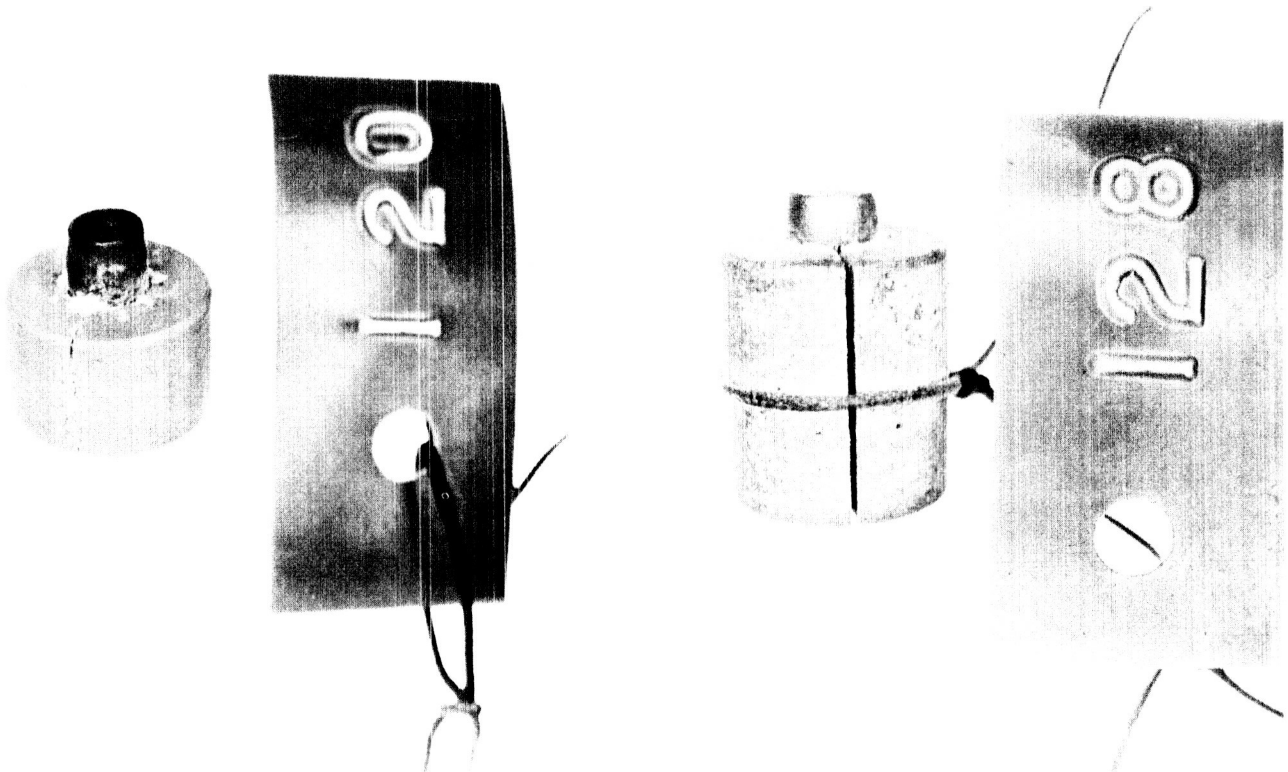


Figure No. 29 Solid and Semi-blind Rivets of A-286 (Item #120) and Pure Titanium (Item #128) Installed in Cylinders of 7075-T6 Aluminum.

Cylinders apparently failed by stress corrosion after exposure to seacoast atmospheres for 4 and 12 weeks respectively.

(2) Ti 6Al-4V Cylinders

Bare 6-4 titanium cylinders appear to show good resistance to corrosion in conjunction with A-286 fasteners, although red rust was noted at the bearing surface after 2 1/2 months in salt spray.

f. Pure Titanium

(1) 7075 Aluminum Cylinders

The aluminum cylinders with the chemical conversion coating and Zn Cr_2O_3 showed good resistance to corrosion in conjunction with pure titanium rivets. It also appears that 7075 aluminum is susceptible to stress corrosion in conjunction with pure titanium under seacoast atmospheric conditions. The specimen shown in Figure 29 failed after 12 weeks.

g. U-212 Fasteners

The corrosion resistance properties of U-212 fasteners in conjunction with structural materials of aluminum and titanium appeared to be slightly better than those exhibited by A-286 fasteners under the same conditions previously mentioned. Anodized and alodined 7075 aluminum showed no indication of corrosion under seacoast environment with U-212 fasteners.

h. Ti 1Al-8V-5Fe

The corrosion resistance properties of 1-8-5 titanium fasteners in conjunction with 7075 aluminum and 321 stainless steel structural materials are about the same as those properties exhibited by 7-12 Ti and 6-4 Ti fasteners except in the case of bare and anodized aluminum cylinders which appear to be susceptible to stress corrosion under seacoast atmospheres. Shown in Figure 30 is a bare 1-8-5 titanium tension bolt installed in bare 7075 aluminum and exposed to seacoast environment for 8 weeks.

i. Inconel 718

The corrosion resistant properties of this nickel base alloy were about equal to those properties exhibited by Waspaloy material.

Photographs of all tested assemblies except the ones still at the shore are shown in Figures 31 through 36. Also, the results of all corrosion tests are shown in Tables 17 and 18.

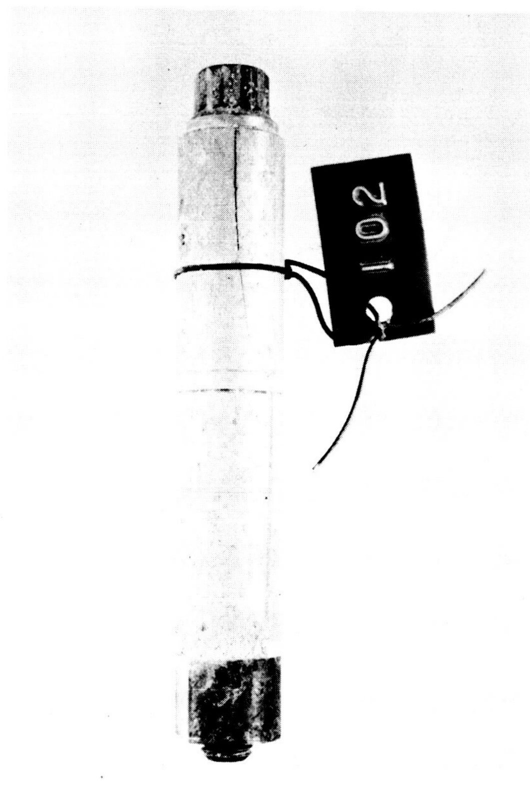


Figure No. 30 Ti 1Al-8V-5Fe Tension Bolt Installed in 7075-T6 Aluminum Cylinder.

Failure was apparently due to stress corrosion. Specimen was exposed to seacoast atmosphere for 8 weeks.

TABLE 17

RESULTS OF SEA COAST ENVIRONMENTAL CORROSION TESTS

Fastener Material	Fastener Coating	Structural Material	Material Structural Coating	Remarks
AISI H-11	Bare	7075 Al	Bare	Heavy red rust on fastener after 2 weeks.
	Cadmium Plated	7075 Al	Mil-A-8625	Flaking of cadmium plate on bolt serration 16 weeks.
	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Flaking of cadmium plate onbolt serration 16 weeks.
	Bare	321 S/S	Bare	Heavy red rust on fastener after 2 weeks.
	Nickel Plated	321 S/S	Bare	Slight red rust on fastener after 2 weeks.
	Bare	Ti6Al-4V	Bare	Heavy red rust on fastener after 2 weeks.
	Nickel Plated	Ti6Al-4V	Bare	Slight red rust on fastener after 2 weeks.
Waspaloy	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface of cylinder - 4 weeks.
	Cadmium Plated	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface of cylinder - 10 weeks.
	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Flaking of cadmium plate on nut serration - 12 weeks.
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface of cylinder - 2 weeks.
	Cadmium Plated	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface of cylinder - 6 weeks.
	Cadmium Plated	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ at bolt bearing surfaces of cylinder - 6 weeks.
	Bare	321 S/S	Bare	Slight red rust at bearing surfaces of cylinder - 10 weeks.
	Bare	Ti6Al-4V	Bare	No indications
Ti7Al-12Zr	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface of cylinder - 2 weeks.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface of cylinder - 10 weeks.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface of cylinder - 4 weeks.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface of cylinder - 6 weeks.
	$ZnC4_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	Red rust at head bearing surface - 6 weeks.
Ti6Al-4V	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - 8 weeks.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 8 weeks.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface - 4 weeks.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 4 weeks.
	$ZnCr_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	Red rust at cylinder joint - 12 weeks.
A-286	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - 2 weeks.
Bolt	Cadmium Plated	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 2 weeks.
Bolt	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 2 weeks.
Bolt	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ at nut bearing surface - 8 weeks.
Rivet	Bare	7075 Al	Mil-A-8625	Failed in stress corrosion in 4 weeks.
Rivet	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
Rivet	Bare	Ti6Al-4V	Bare	Light red rust on swaged collar - 2 weeks.
Bolt	Bare	Ti6Al-4V	Bare	Light red rust on bolt serrations - 2 weeks.
Nut with 6-4 Ti	Silver Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Light red rust on nut - 4 weeks.
Nut with 7-12 Ti	Silver Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Light red rust on nut - 4 weeks.
2024 Al nut with	Mil-A-8625	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin noted on twist off nut - 10 weeks.
6-4 Ti bolt	Nut / Bolt			
2024 Al nut with	Mil-A-8625 / $ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin noted on twist off nut - 16 weeks.
6-4 Ti bolt	Mil-A-8625 / $ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin noted on twist off nut - 16 weeks.
2024 Al nut with	Mil-A-8625 / Cad. Plate	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin noted on twist off nut - 10 weeks.
AISI 8740 bolt	Mil-A-8625 / Cad. Plate	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin noted on twist off nut - 12 weeks.
Pure Ti	Bare	7075 Al	Bare	Light $Al(OH)_3$ at bearing surfaces - 2 weeks Apparent stress corrosion of cylinder - 14 weeks.
	Bare	7075 Al	Mil-A-8625	Same as Bare 7075 Al
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	2219 Al	Bare	Light $Al(OH)_3$ at bearing surfaces - 2 weeks.
	Bare	2210 Al	Mil-A-8625	Light $Al(OH)_3$ at bearing surface - 2 weeks.
	$ZnCr_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	Red rust at bearing surface of S/S - 4 weeks.
U-212	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface of cylinders - 2 weeks.
	Cd. Plated	7075 Al	Mil-A-8625	No indications.
	Cd. Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	Ti6Al-4V	Bare	Light red rust at bearing surfaces - 8 weeks.
Ti1Al-8V-5Fe	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - 2 weeks - cylinder cracked -12wks
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 4 weeks - cylinder cracked -14wks
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	Red rust at joint surface - 12 weeks.
Inco 718	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - 2 weeks.
	Cd. Plated	7075 Al	Mil-A-8625	No indications
	Cd. Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications
	Bare	Ti6Al-4V	Bare	No indications

Vasco Max. 300 - Results were similar to those of H-11 fasteners and structural material.

TABLE 18

RESULTS OF ACCELERATED SALT SPRAY (5% Na Cl) CORROSION TESTS

Fastener Material	Fastener Coating	Structural Material	Structural Material Coating	Remarks
AISI H-11	Bare	7075 Al	Bare	Heavy red rust on bolt and nut - one day.
	Cadmium Plated	7075 Al	Mil-A-8625	Al $(OH)_3$ on end of cylinder - 9 days.
	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Nut turning black - 9 days.
	Bare	321 S/S	Bare	Heavy red rust on bolt and nut - one day.
	Nickel Plated	321 S/S	Bare	Red rust or bolt threads - ona day.
	Bare	Ti6Al-4V	Bare	Heavy red rust on bolt and nut - one day.
	Nickel Plated	Ti6Al-4V	Bare	Red rust on bolt threads - one day.
Waspaloy	Bare	7075 Al	Bare	Al $(OH)_3$ gelatin at bearing surface - one day.
	Cadmium Plated	7075 Al	Mil-A-8625	Al $(OH)_3$ gelatin at bearing surface - 4 weeks.
	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Discoloration at bearing surface - light $Al(OH)_3$ 8 weeks.
	Bare	2219 Al	Bare	Al $(OH)_3$ gelatin at bearing surface - one day.
	Cadmium Plated	2219 Al	Mil-A-8625	Al $(OH)_3$ gelatin at bearing surface - 7 days.
	Cadmium Plated	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	Discoloration at bearing surface - light $Al(OH)_3$ - 4 weeks.
	Bare	321 S/S	Bare	Discoloration at bearing surface - 8 days.
	Bare	Ti6Al-4V	Bare	Discoloration at bearing surface - 8 days.
Ti7Al-12Zr	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - one day.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 4 days.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ at bearing surface - 8 days.
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface - one day.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - one day.
	$ZnCr_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No Indications
	Bare	321 S/S	Bare	
Ti6Al-4V	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - one day.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 3 days.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications of $Al(OH)_3$ - head discoloration - 6 weeks
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface - one day.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - one day.
	$ZnCr_2$) 3	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indication of $Al(OH)_3$
	Bare	321 S/S	Bare	
A-286	Bare	7075Al	Bare	$Al(OH)_3$ gelatin at bearing surface - 3 days.
Bolt	Cadmium Plated	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin at bearing surface - 3 days.
Bolt	Bare	7075 Al	Mil-A-8625	
Bolt	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ at nut bearing surface - 6 days.
Rivet	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surfaces - 2 days.
Rivet	$ZnCr_2\ O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Slight indication of $Al(OH)_3$ - 4 weeks no heavier - 12 weeks.
Rivet	Bare	Ti6Al-4V	Bare	Light red rust on head - one day - remove after one month.
Bolt	Bare	Ti6Al-4V	Bare	Light red rust on nut - 3 days - no change - 6 weeks.
Nut with 6-4Ti bolt	Silver Plate	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Slight red rust on nut - 3 days.
Nut with 7-12 Tibolt	Silver Plate	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Slight red rust on nut - one day.
2024 Al with	Mil-A-8625	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin on twist off nut - one day.
6-4 Ti Bolt	Nut / Bolt			
2024 Al with	Mil-A-8625 / $ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2\ O_3$	$Al(OH)_3$ gelatin on twist off nut - 6 weeks.
6-4 Ti Bolt	Mil-A-8625 / $ZnCr_2O_3$	7075 Al		
2024 Al nut with	Mil-A-8625 / Cd. Plate	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin on twist off nut - 8 days.
AISI8740 Bolt	Mil-A-8625 / Cd. Plate	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin on twist off nut - 9 days.
Pure Ti	Bare	7075 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - one day.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin on bearing surface - 2 days.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications
	Bare	2219 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - 3 days.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ gelatin at bearing surface - 3 days.
	Zn Cr_2O_3	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications
	Bare	321 S/S	Bare	Red rust at bearing surface - 7 weeks.
U-212	Bare	7075 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - one day.
	Cd. Plated	7075 Al	Mil-A-8625	Discoloration of bolt head - one week.
	Cd. Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Discoloration of bolt head - one week.
	Bare	Ti6Al-4V	Bare	Red rust on nut and bolt - 7 days.
Ti1Al-8V-5Fe	Bare	7075 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - one day.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin at bearing surface - 5 days.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	No indications.
Inco 718	Bare	7075 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - one day.
	Cd. Plated	7075 Al	Mil-A-8625	Discoloration at bearing surfaces - no other indications.
	Cd. Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Flaking of Cd. Plate - 7 weeks.
	Bare	Ti6Al-4V	Bare	Slight red rust at joints - 14 days.

Vasco Max. 300 - Results were similar to those of H-11 fasteners and structural material.

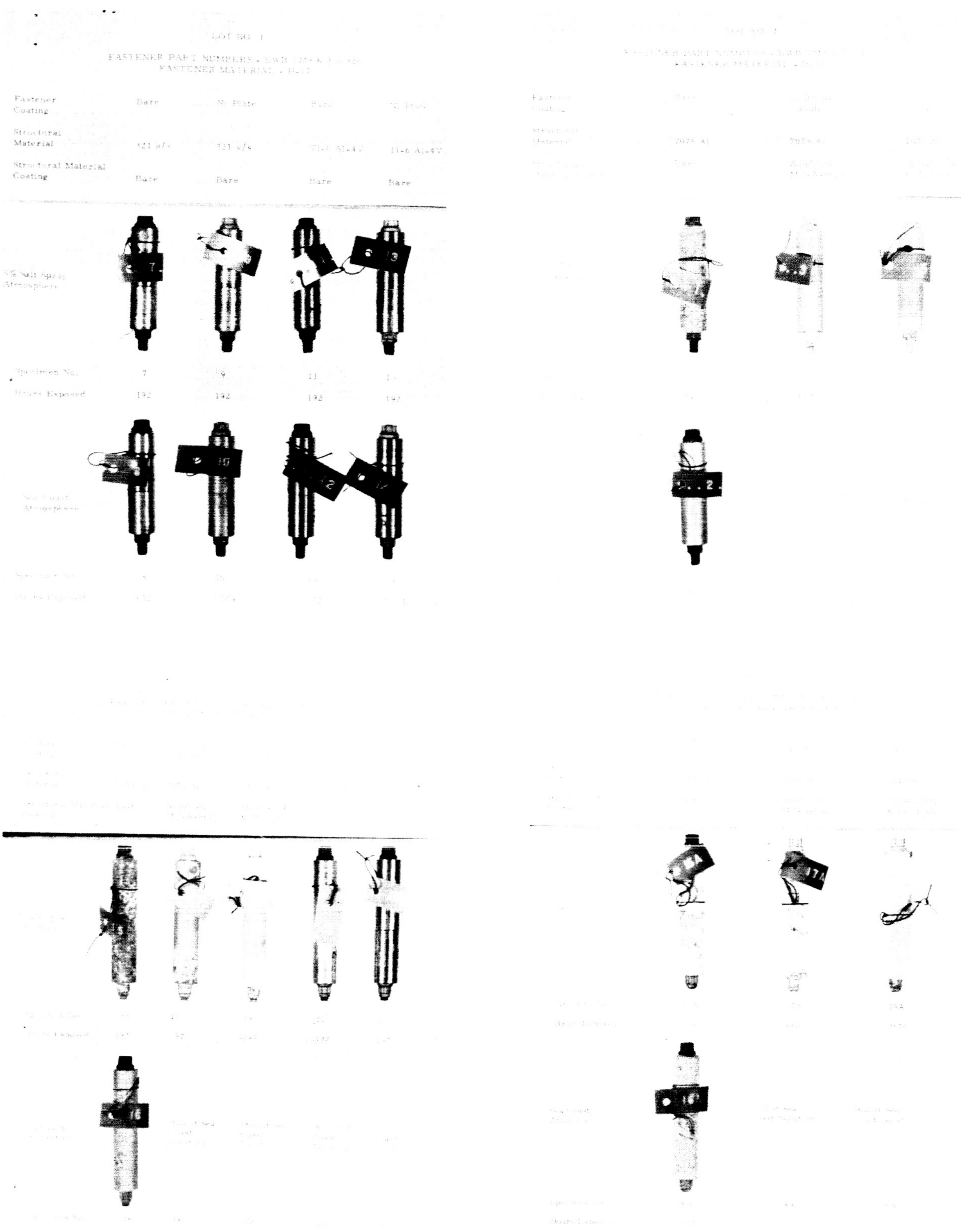
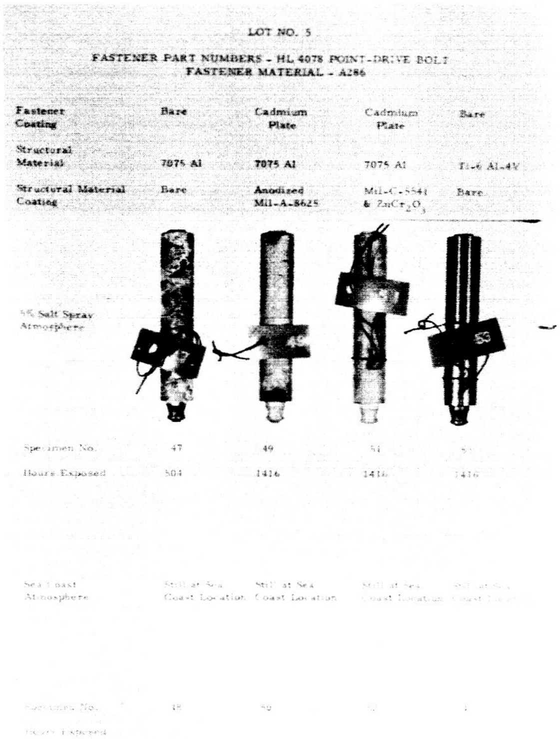
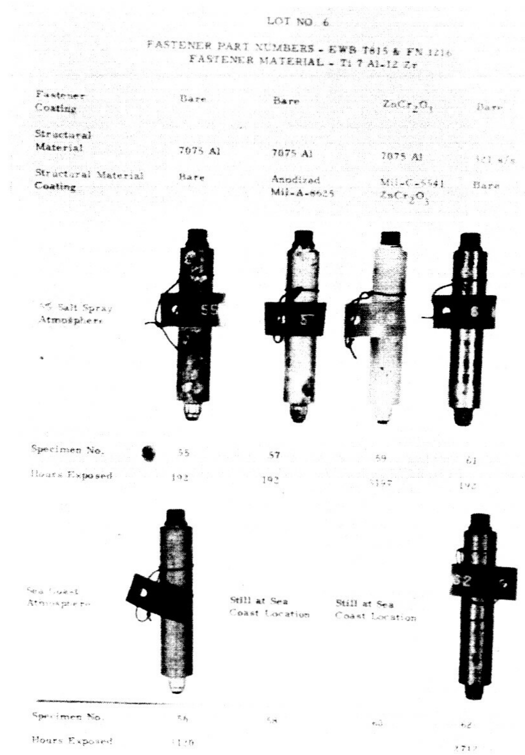
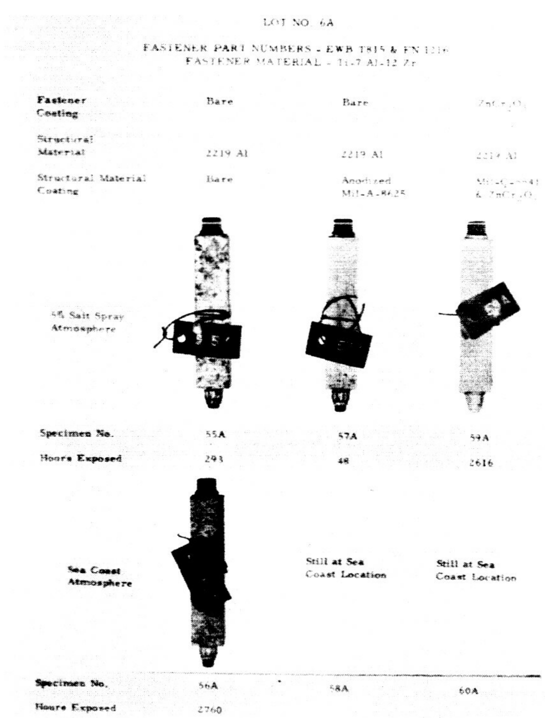


Figure No. 31 Photomacrograph of Specimens Exposed to Sea Coast and Accelerated Salt Spray Atmospheres

Figure No. 32 Photomacrographs of Specimens Exposed to Sea Coast and Accelerated Salt Spray Atmospheres







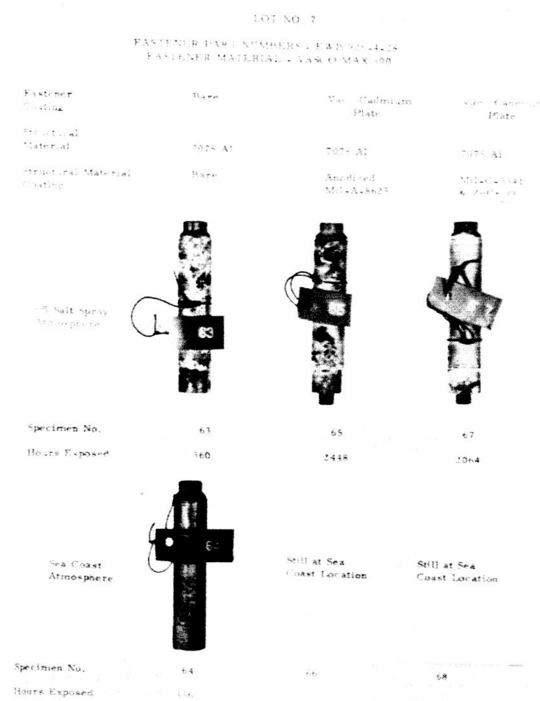


Figure No. 33 Photomacrographs of Specimens Exposed to Sea Coast and Accelerated Salt Spray Atmospheres

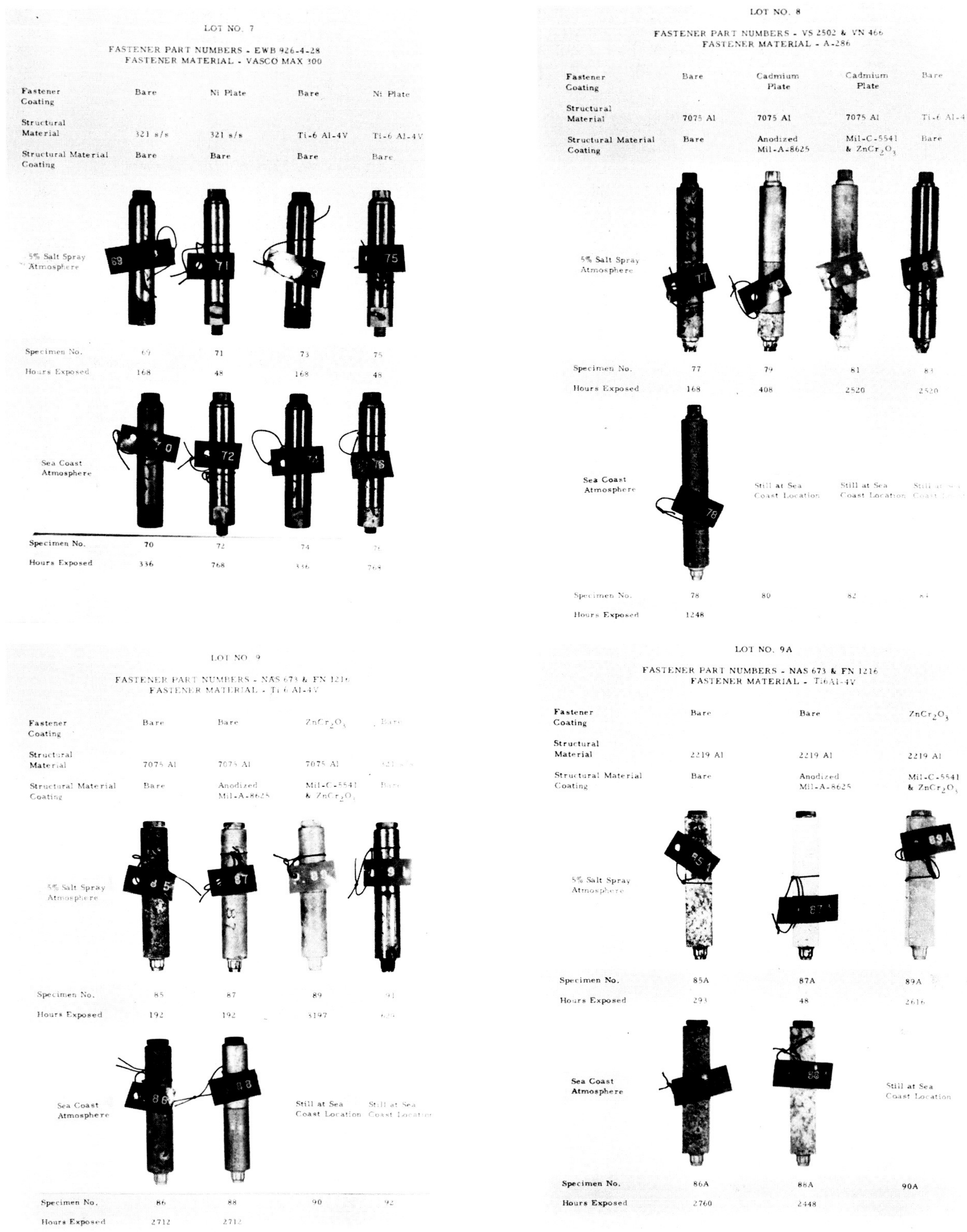


Figure No. 34 Photomacrographs of Specimens Exposed to Sea Coast and Accelerated Salt Spray Atmospheres

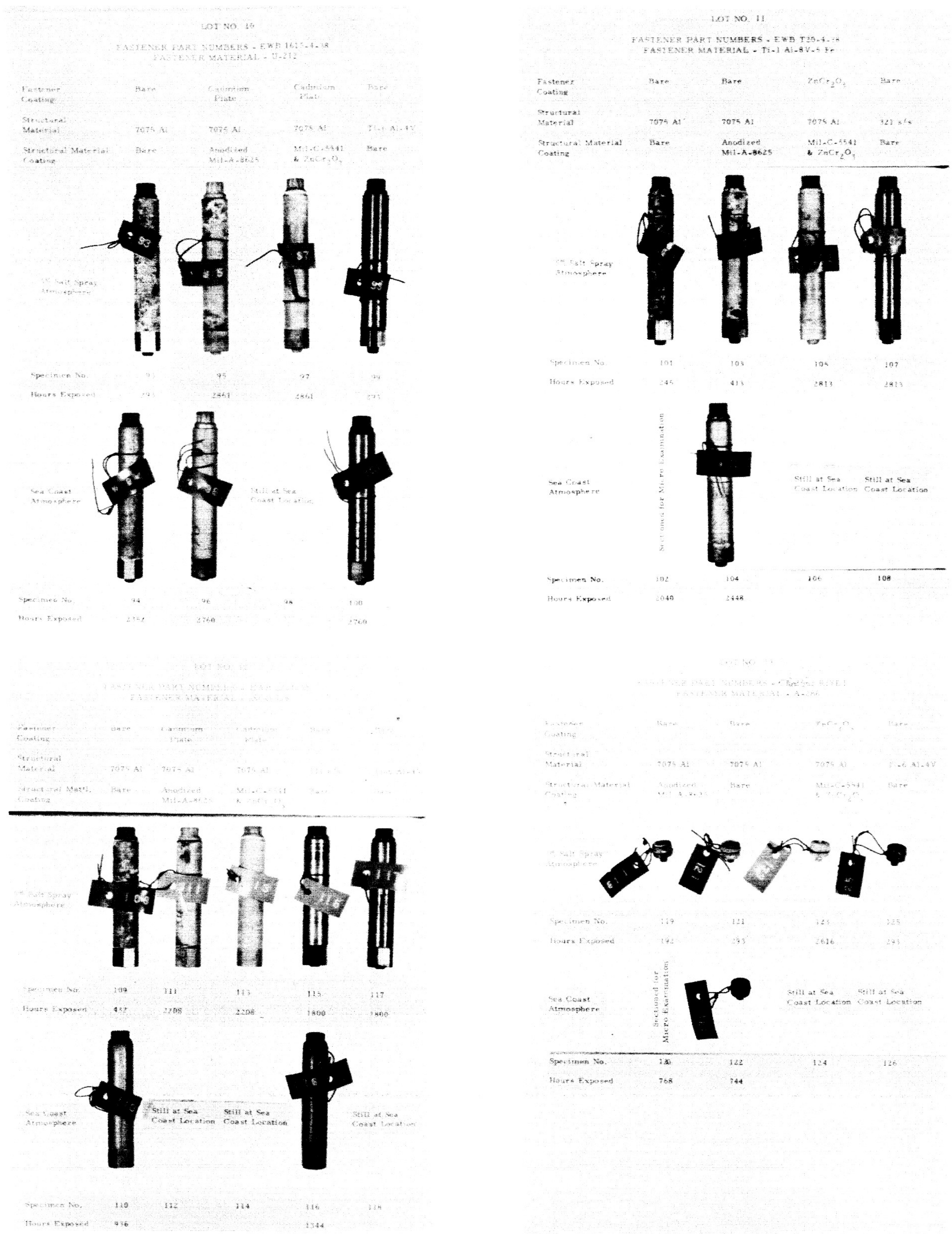


Figure No. 35 Photomacrographs of Specimens Exposed to Sea Coast and Accelerated Salt Spray Atmospheres

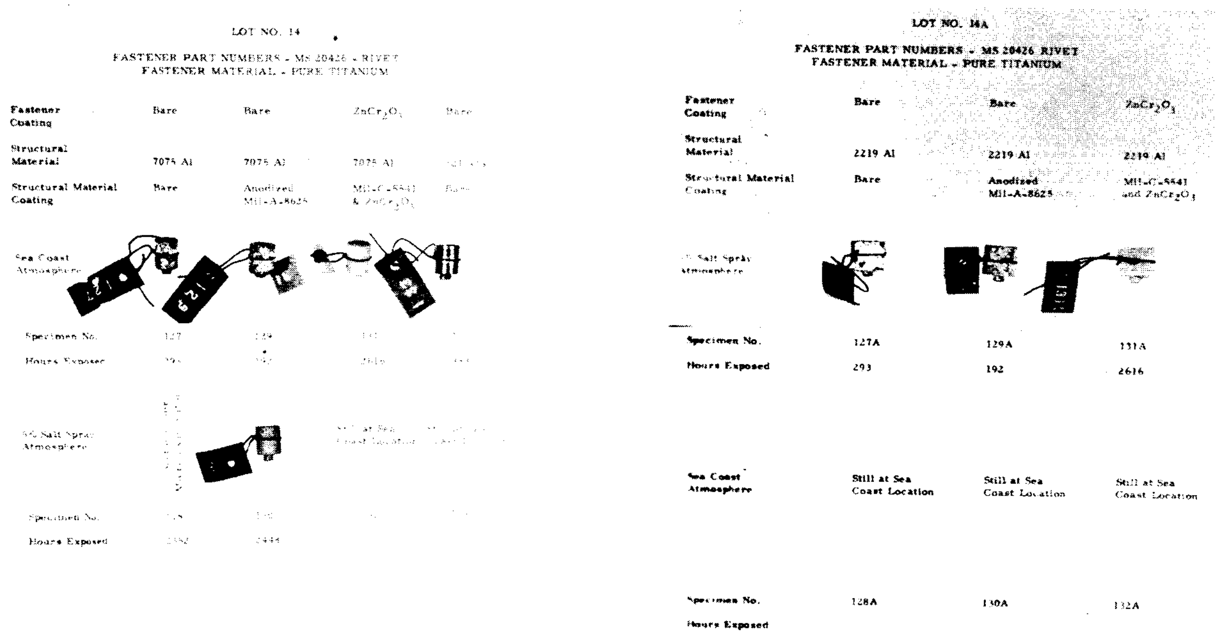


Figure No. 36 Photomacrographs of Specimens Exposed to Sea Coast and Accelerated Salt Spray Atmospheres

SECTION IV

UNIQUE TESTS FOR FASTENERS FOR SPACE VEHICLES

The objective of this phase of the program was to determine, through the survey, what special tests were required to insure reliability in fasteners to be used in the unique conditions experienced by space vehicles. These tests were then to be conducted, and if the tests were significant, to be suggested for incorporation into either new or existing specifications.

A. RESULTS OF SURVEY

From the survey it was determined that space vehicles, as presently conceived, would encounter several load conditions and environments not generally experienced by commercial machinery or aircraft. Some of these are:

1. Severe cryogenic temperatures to -423° F.

2. Extremely fast rate of heating or cooling.

3. Outer space conditions of vacuum, magnetic fields, and radiation.

The net result was that the following were suggested for detailed investigation:

1. Mechanical properties of fastener shear and tensile strength at liquid hydrogen temperatures of -423° F.

2. Impact properties at cryogenic temperatures.

3. Effects of cryogenic thermal cycling on the mechanical properties.

4. Stress corrosion properties when used in conjunction with cryogenics, lubricants, structural materials, and fuels.

5. Reactions to liquid fuels such as LH2, LOX, and FLOX.

6. Effects of radiation and vacuums.

7. Magnetic properties.

B. DISCUSSION OF WORK ACCOMPLISHED

Of the work indicated by the above list, some was completed, some was considered outside the scope of this contract, and some will be considered during the following year.

1. Mechanical Properties at -423° F

The tensile, yield, and shear strengths of all the fastener combinations and their base alloys were determined at -423° F in liquid hydrogen. The value of these tests was demonstrated by the variation in results. In cases of severe embrittlement, all strength values fell below those at room temperature. And where there was no indication of embrittlement, the properties at -423°F increased over those at room temperature.

In addition to these two clear cut cases, some fasteners showed an increased tensile strength at -423°F while the shear strength at the same temperature decreased below room temperature properties. The conclusion is that fasteners to be utilized at -423°F should be inspection tested at -423°F in tensile and shear. Requirements based on statistical sampling should be added to existing specifications.

2. Thermal Cycling to -423°F

The results of thermal cycling loaded fasteners between -423°F and room temperature are discussed in other sections. The conclusions were that there were neither mechanical nor metallurgical effects. For this reason, no requirement need be added to any fastener specifications.

3. Thermal Cycling to Elevated Temperature

The loaded fasteners were also thermal cycled from room temperature to the maximum utilization temperature of the fastener combination. The chief concern was the very fast rate at which the fasteners were heated. Fast heating proved to be no different from slow heating. Also, the mechanical results proved no different than was expected after static exposure at the same time and temperature. No additional specification requirements are needed to cover high temperature thermal cycling.

4. Stress Corrosion

A program described elsewhere in this report was conducted to determine the fastener stress corrosion susceptibility with various combinations of lubricants, corrosion barriers, coatings, and structural alloys. This was done in a salt spray cabinet and at the oceanside. While there was no straight line correlation of the results obtained by both methods, in some cases the results obtained in the seaside tests were more severe than the salt spray cabinet tests. The designer of aerospace vehicles should be sure that the fastener joint has been tested in a seaside atmosphere to insure stress corrosion reliability of the joint design. The many combinations of joint design do not lend easily to incorporating stress corrosion requirements into fastener specifications.

C. FUTURE WORK

The testing at -423°F showed some interesting results. Some materials, such as H-11, have an increase in material strengths, bolt ultimate and bolt shear strength. On the surface this would appear to make H-11 a usable material at -423°F, but other data on charpy specimens indicate poor resistance to impact at the cryogenic temperatures. It becomes clear that other tests are needed to determine the future of these fasteners at -423°F. Tests in Phase IV of this program indicate that V-notch with a K_t8 does not tell the story either.

Tests to be conducted on the bolts of Phase II are:

1. Angle block tests at -320°F and at -423°F. Angle will be placed at bearing surface of the nut to determine dual effect of increased localized stress and cryogenic temperature.

2. Tension impact of the bolts at -320°F, and if practical, at -423°F.

3. Vibration of the loaded nut-bolt combinations at -320°F.

4. Tension-tension fatigue at room temperature.

Fasteners showing positive results under all these conditions should be applicable for use at -423°F.

SECTION V

PHASE IV - POTENTIAL HIGH STRENGTH FASTENER MATERIALS EVALUATION

As a result of the survey, the five materials shown in Table 19 were selected in conjunction with the Contracting Officer's Technical Representative for evaluation as potential high strength fastener alloys. The materials selected fall within the base alloy groups of titanium, iron, and nickel. The alloys are either new alloys or modifications of existing alloys.

A. MANUFACTURING

The five alloys were fabricated into 1/4-28 twelve point tension bolts with the exception of the 25 per cent cold reduced Waspaloy material which was made into studs with 1/4-28 threads at both ends.

Slugs with 1/2 inch outer diameter and 1/4-28 internal threads were used as companion nuts. The nuts were fabricated from the same material as the companion bolt or stud, and employed the same heat treatment. Figure 37 depicts the selected materials fabricated into the form of fasteners for evaluation.

Manufacturing and heat treat processes were as follows:

1. Ti 1Al-8V-5Fe

a. Hot forged 12 point head
b. Solution treated - 1425°F - 1 hr water quenched
c. Age hardened - 950°F - 2 hrs air cooled
d. Rolled threads.

2. U-212

a. Hot forged 12 point head
b. Solution treated - 1850°F - 2 hrs water quenched
c. Rolled threads
d. Stabilized - 1425°F - 2 hrs air cooled
e. Age hardened - 1250°F - 16 hrs air cooled.

3. VascoMax 300

a. Hot forged 12 point head
b. Solution treated - 1500°F - 1 hr air cooled
c. Age hardened - 900°F - 3 hrs air cooled
d. Rolled threads.

4. Inconel 718

a. Hot forged 12 point head
b. Solution treated - 1800°F - 1 hr water quenched
c. Rolled threads
d. Age hardened - 1325° F - 8 hrs - furnace cooled to 1150° F - held 8 hrs air cooled.

5. Waspaloy

a. Solution treated - 1900° F - 1 hr water quenched
b. Cold extruded 25 per cent (.312 inches to .268 inches)
c. Age hardened - 1400° F - 16 hrs air cooled
d. Rolled threads.

Listed in Table 20 are the chemical compositions of the five materials evaluated.

TENSION FASTENERS - PHASE IV

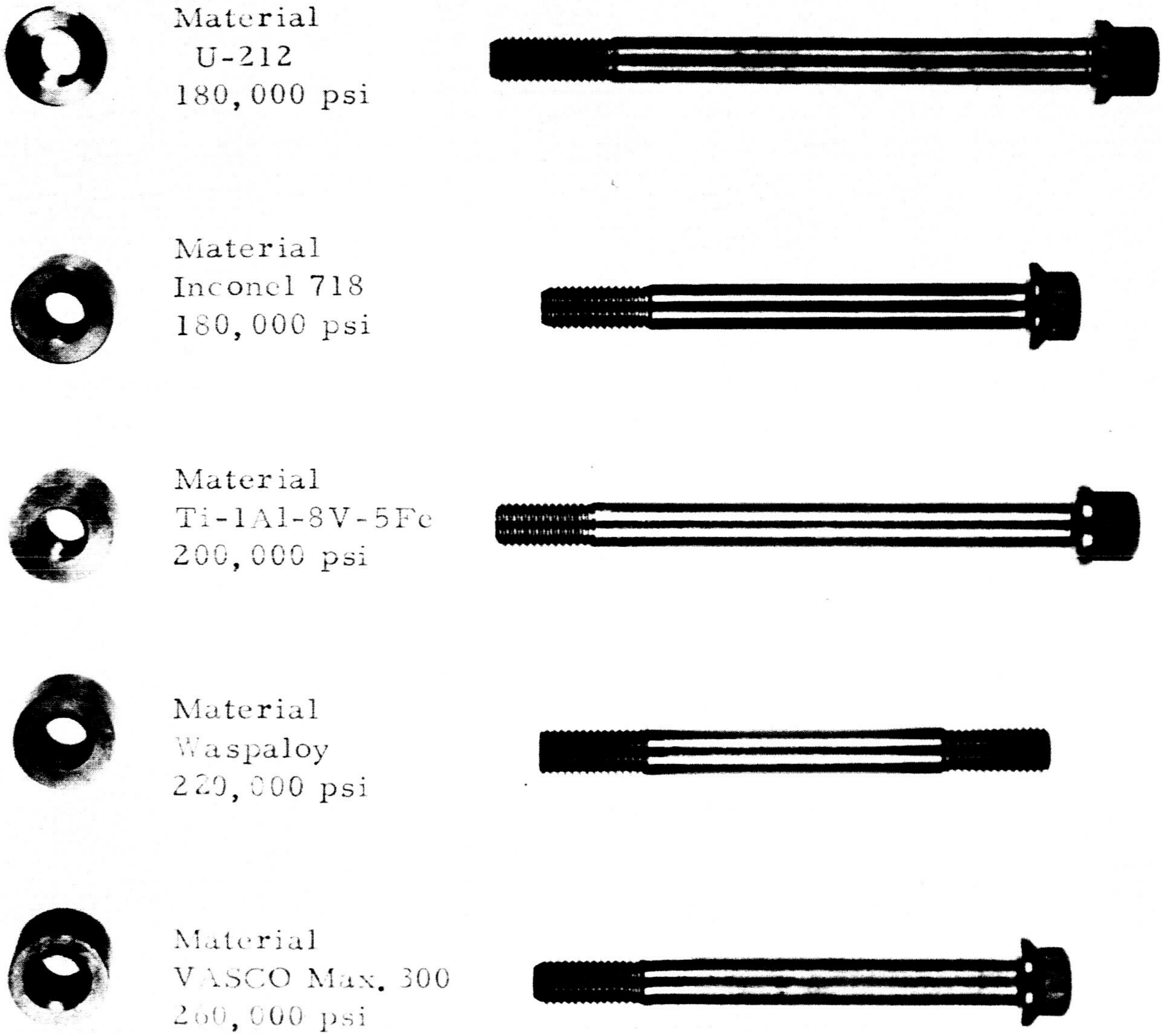


Figure No. 37 Composite Photograph of Tension Fasteners Evaluated in Phase IV

TABLE 19

POTENTIAL HIGH STRENGTH FASTENER MATERIALS EVALUATED IN PHASE IV

Material	Base Alloy	Supplier	Fastener Configuration	Thread Form	Plating	Min. UTS @70°F-ksi	Max. Util. Temp. °F
Ti 1Al-8V-5Fe	Titanium	Reactive Metals Products	12 Pt Tension Bolt	Mil-S-8879		200	300
U-212	Iron	Universal Cyclops	12 Pt Tension Bolt	Mil-S-8879		180	1200
VascoMax 300	Iron	Vanadium Alloys	12 Pt Tension Bolt	Mil-S-8879	AMS 2416	260	900
Pyromet 718	Nickel	Carpenter Steel	12 Pt Tension Bolt	Mil-S-8879		180	1200
25% Cold Red. Waspaloy	Nickel	Carpenter Steel	Stud	Mil-S-8879		220	1400

TABLE 20

CHEMICAL COMPOSITION OF MATERIALS EVALUATED IN PHASE IV

Material	Heat No.	C	Mn / H	Si / N	P / O	S	Cr	Ni	Mo	Ti	Al	Cr	B	Cb Ta	Co	Zr	Ca	Fe	V
Ti 1Al-8V-5Fe	30106	.03	41/49	.011	.36						1.7							4.9	7.5
U-212	KA1661	.087	.05	.038	.003	.005	16.10	25.24		3.98	.038		.066	.44					
VascoMax 300	07144	.03	.06	.08	.004	.008		18.95	4.79	.59	.10		.002		8.95	.006	.05		
Pyromet 718	V-90108	.07	.15	.23	.016	.008	18.92	52.62	2.98	1.01	.70	.01	.0046	5.65					
Waspaloy	V-11968	.07	.03	.08	.004	.007	19.57	57.33	4.45	2.92	1.21	.01	.004		13.22	.08		.34	

B. TEST PROGRAM

The test program for the evaluation of potential high strength fastener materials is shown in Figure 38. Except where noted, the test procedures were the same as those described in Section III.

1. Tensile

a. Bolts

Tensile tests to determine ultimate strength and yield strength were conducted at -423°F, room temperature, and maximum utilization temperatures.

b. Smooth Specimens

To evaluate the base alloy from which the bolts were fabricated, standard .113 inches tensile specimens made from the bolts were tested at -423°F, room temperature, and maximum utilization temperature. Percentage of Elongation was determined using a .50 inch gage length.

c. V-Notch Specimens

The notch to smooth tensile relationship of the alloy from which the bolts were manufactured was determined. V-notch specimens with a stress concentration factor of Kt8, as shown in Figure 39, were tested at the same temperatures as the smooth specimens.

2. Double Shear

Double shear tests were conducted at -423°F, room temperature, and maximum utilization temperature.

3. Stress Rupture

Stress rupture properties for ten hours were determined at the maximum utilization temperature of the bolt.

4. Stress Relaxation

Residual stresses were determined for 50 hours' exposure at maximum utilization temperature employing one initial preload. The initial preload was 80 per cent of the room temperature torque versus induced load yield strength of the fastener assembly.

5. Corrosion Resistance

Corrosion resistance tests were conducted under seacoast and accelerated salt spray atmospheric conditions.

6. Coefficient of Thermal Expansion

Coefficients of thermal expansion were derived from data supplied by the Jet Engine Department of the General Electric Propulsion Laboratory.

TEST PROGRAM - PHASE IV

EWB TENSION BOLTS

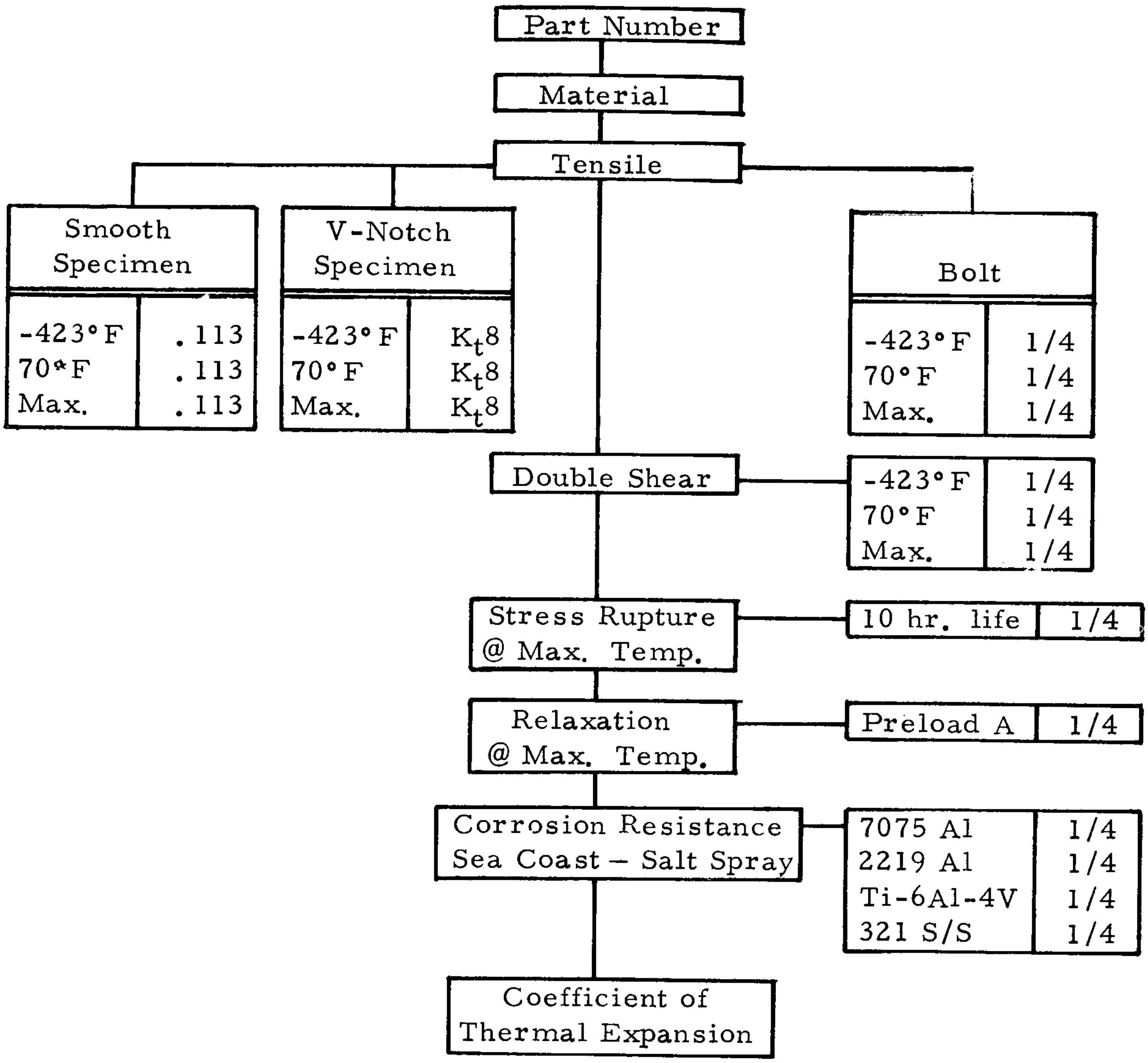
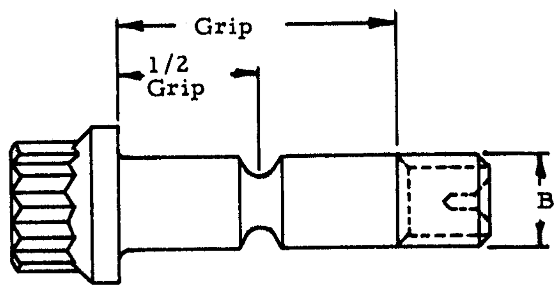
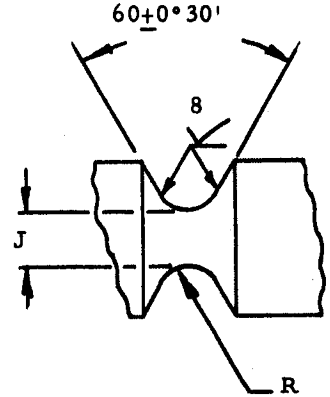


Figure No. 38

PD 300 61036

REVISION AND DATE





V- NOTCH DETAIL

ITEM	B +.000 -.001	J ±.0005	R +.0000 -.0003
1	.250	.1765	.001

Note - 1. Diameter "J" to be concentric with diameter "B" within .001 TIR.

V-NOTCH SPECIMEN
FOR NASA CONTRACT NAS8-11125
STRESS CONCENTRATION FACTOR = $K_t 8$

TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH

DRAWN BY J. Glackin
DATE 2-20-64

STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA

MATERIAL AND HEAT TREAT

Figure 39

C. DISCUSSION OF RESULTS

1. Ti 1Al-8V-5Fe

The 185 titanium alloy is not suitable for cryogenic fastener application. At -423° F, the material becomes brittle and extremely notch sensitive. The tensile and double shear results show a significant decrease in both thread strength and shear strength compared to room temperature strengths. The V-notch tests (K_t8) showed a .24 notched to unnotched tensile ratio at -423° F compared to 1.10 at room temperature. Results at -320°F were similar to those at -423° F.

2. U-212

Fasteners fabricated from U-212 alloy showed definite suitability for cryogenic utilization to -423° F. This material possesses excellent strength and notch ductility over the entire temperature range of -423° F to 1200° F. It should be noted that the ductility of U-212 material was higher at -423°F than at room temperature.

3. Vasco Max 300 (18% Ni Maraging Steel)

Fasteners made from Vasco Max 300 alloy could be utilized in a limited capacity at -423° F -- primarily for tension applications. This material had the highest bolt and material tensile strength of the five alloys tested; however, shear strength at -423°F decreased significantly in comparison to room temperature shear strength. The shear to ultimate ratio at -423°F was .35 compared to .62 at room temperature.

The notch geometry appears to have an effect on Vasco Max 300 alloy at -423° F. Tensile tests at -423°F of V-notch specimens (K_t8) showed a significant decrease in strength below room temperature properties, but the thread strength of fasteners increased significantly at the same temperature. As previously mentioned, this material was employed for cryogenic double shear fixtures and proved unsatisfactory in the testing of large diameters.

4. Inconel 718

Fasteners fabricated from Inconel 718 alloy showed considerable promise for cryogenic application. The alloy has excellent strength and notch ductility over the entire temperature range of -423°F to 1200°F.

5. 25% Cold Reduced Waspaloy

Waspaloy material cold reduced to a 220 ksi stress level showed definite promise for cryogenic fastener application down to -423°F. The material has excellent strength and notch ductility over the entire temperature range of -423°F to 1400°F.

Further work is required to develop a method for heading this material without destroying the benefits of the cold work and to develop an age hardening process that would eliminate the strain age cracking that occurs during heat treatment. Figure 40 shows a blank of 30 per cent cold reduced Waspaloy after age hardening. No cracks were evident before age hardening. The reduction was dropped to 25 per cent but cracks were still evident on some of the extruded and aged blanks. A sufficient number showed no indication of cracks, therefore the evaluation of this alloy was conducted.

As a result, the problems of heading and age hardening cold reduced Waspaloy remain to be solved before high strength Waspaloy can be utilized for space vehicle fastener applications.

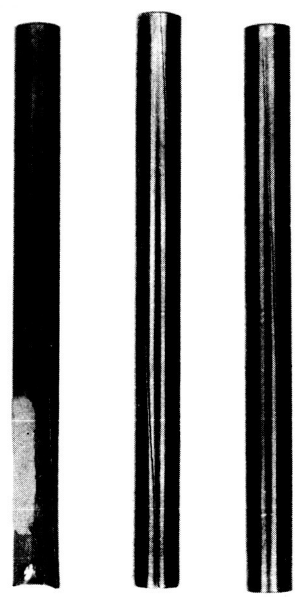


Figure No. 40 Photomacrograph of 30 percent Cold Extruded and Aged Waspaloy Material

SECTION VI

CONCLUSIONS

A. SURVEY

1. The seventy to ninety per cent of structural applications involve shear loading. The majority of engine applications involve tensile loading.

2. A-286 appears to be the most commonly used fastener material in strength levels ranging from 140 ksi through 200 ksi.

3. Strength to density ratios of fasteners are becoming increasingly important.

4. High temperature applications are comparatively few in number, and concentrated in the areas of engines, structural areas in the vicinity of engines, and re-entry vehicles. A-286 and Waspaloy alloys dominate the field.

5. Aluminum fasteners are confined to rivets.

6. The survey showed that very little data exist on the cryogenic properties of fasteners, particularly at -423°F.

B. FASTENER AND POTENTIAL HIGH STRENGTH FASTENER EVALUATION

1. Corrosion resistant iron base alloys, nickel base alloys, and aluminum base alloys showed definite suitability for space vehicle applications from -423°F to their respective maximum utilization temperatures.

2. Fasteners fabricated from AISI H-11 alloy heat treated to a 220 ksi stress level and the titanium alloys of standard Ti 6Al-4V and Ti 7Al-12Zr, could be considered for cryogenic applications down to -423°F in shear only if combined bending is not prevalent. These materials do not exhibit a yield strength as fasteners.

3. Diameter appears to have a significant effect on the mechanical properties of fasteners at cryogenic temperatures. Increasing diameters in all materials showed a decrease in mechanical properties at -423°F.

4. The locking characteristics of nuts were not affected by thermal cycling at both temperature extremes.

5. Thermal cycling at cryogenic and elevated temperatures does not affect the mechanical properties and microstructure of fasteners and materials except for preload, which decreases because of normal stress relaxation. The speed of temperature application had no effect on the mechanical properties.

6. Stress relaxation at maximum temperatures does not affect the bolt properties except in the cases of A-286 and Waspaloy fasteners where over-aging and additional aging are encountered.

7. Corrosion resistance is greatly enhanced by a coating of zinc chromate primer ($Zn\ Cr_2\ O_3$), particularly with titanium fasteners in conjunction with aluminum structural material.

8. 7075-T6 aluminum structural material appears to be susceptible to stress corrosion under seacoast environmental atmospheres when used with pure titanium and 185 titanium fasteners.

9. The determination of a material susceptibility to stress corrosion should be conducted under conditions that closely approximate actual usage. Indications of stress corrosion were noted under seacoast environments, but not in accelerated salt spray.

10. The 18 per cent nickel maraging steel (Vasco Max 300) appears to have limited tensile fastener application at -423° F, because shear strength drops off significantly at -423° F compared to room temperature.

11. Further work in the areas of developing a heading and heat treat process for cold reduced Waspaloy is required before this material can be utilized as a complete fastener.

12. To adjudge the suitability of a fastener at -423° F, the fastener must be tested, since no one test or combination of tests is adequate.

APPENDIX I

TEST RESULTS

TENSION BOLTS - PHASE II

TABLE I

SUMMARY OF RESULTS

EWB TM9 & FN 922 - MATERIAL - H-11 (220 KSI)

Material Properties -

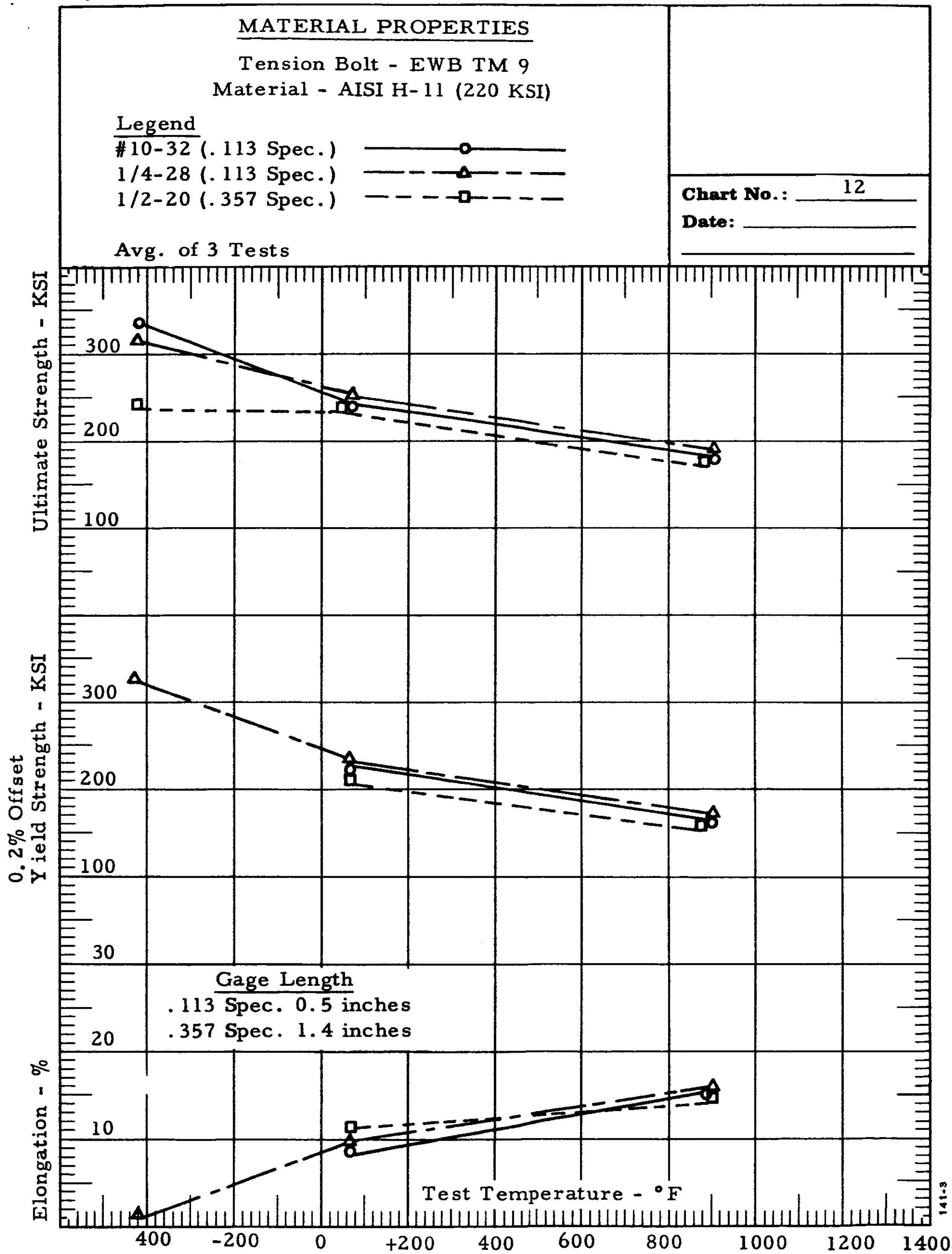
Test Temp.	U. T. S. - KSI #10	U. T. S. - KSI 1/4	U. T. S. - KSI 1/2	0.2% Offset Yield - KSI #10	0.2% Offset Yield - KSI 1/4	0.2% Offset Yield - KSI 1/2	Elongation - % #10	Elongation - % 1/4	Elongation - % 1/2
-423° F	354.8	343.2	220.4	N. Y.	N. Y.	N. Y.	*	2.0	-
	363.6	350.5	271.4	N. Y.	N. Y.	N. Y.	*	2.0	-
	295.5	249.0	226.1	N. Y.	N. Y.	N. Y.	*	*	-
70° F	240.9	244.7	242.7	221.5	239.5	211.0	10.0	10.0	14.2
	248.1	247.4	246.2	240.7	229.5	214.0	10.0	10.0	14.2
	238.3	244.8	241.3	229.6	227.0	209.3	10.0	10.0	12.8
900° F	178.5	181.0	178.5	166.8	172.5	170.0	16.0	18.0	15.7
	179.5	186.8	158.0	175.7	173.0	151.0	14.0	16.0	15.7
	177.8	183.6	175.5	171.0	170.4	165.0	14.0	16.0	17.1

Test Temp.	Reduction of Area -% #10	Reduction of Area -% 1/4	Reduction of Area -% 1/2	Shear Strength - KSI #10	Shear Strength - KSI 1/4	Shear Strength - KSI 1/2
-423° F	*	5.4	2.2	211.6	178.3	Test
	*	5.4	1.1	206.3	176.2	Not
	*	*	1.1	201.0	183.4	Conducted
70° F	51.3	53.0	48.3	154.8	144.8	147.7
	48.8	50.4	47.4	155.3	156.8	143.9
	51.6	51.4	46.0	157.6	156.8	148.2
900° F	59.7	64.8	61.3	105.8	101.9	114.0
	64.3	63.8	66.0	108.4	112.1	115.0
	64.0	63.6	64.7	112.4	114.1	115.2

Bolt & Nut Properties -

Test Temp.	U. T. S. - KSI(1) #10	U. T. S. - KSI(1) 1/4	U. T. S. - KSI(1) 1/2	Johnson's 2/3 Approx. Yield - KSI #10	Johnson's 2/3 Approx. Yield - KSI 1/4	Johnson's 2/3 Approx. Yield - KSI 1/2
-423° F	251.2 (N.S.)	134.0 (N.C.)	111.0 (N.C.)	N. Y.	N. Y.	N. Y.
	245.2 (N.S.)	107.2 (N.C.)	147.2 (N.C.)	N. Y.	N. Y.	N. Y.
	205.1 (N.S.)	322.5	179.5 (H)	N. Y.	N. Y.	N. Y.
70° F	235.0	235.8	233.1 (N.S.)	205.0	180.4	180.6
	234.1	235.0	224.3 (N.S.)	179.7	179.9	177.7
	231.8	232.5	231.9 (N.S.)	179.7	180.4	177.7
900° F	200.0	177.8	184.0	165.9	155.2	161.7
	195.8 (N.S.)	177.8	186.5	147.5	151.4	160.0
	197.0 (N.S.)	180.4	193.5	149.8	152.0	166.0

(1) Stress calculated at basic pitch diameter
N.Y. - No Yield
N.C. - Nut Cracked
N.S. - Nut Stripped
* Broke Outside Gage



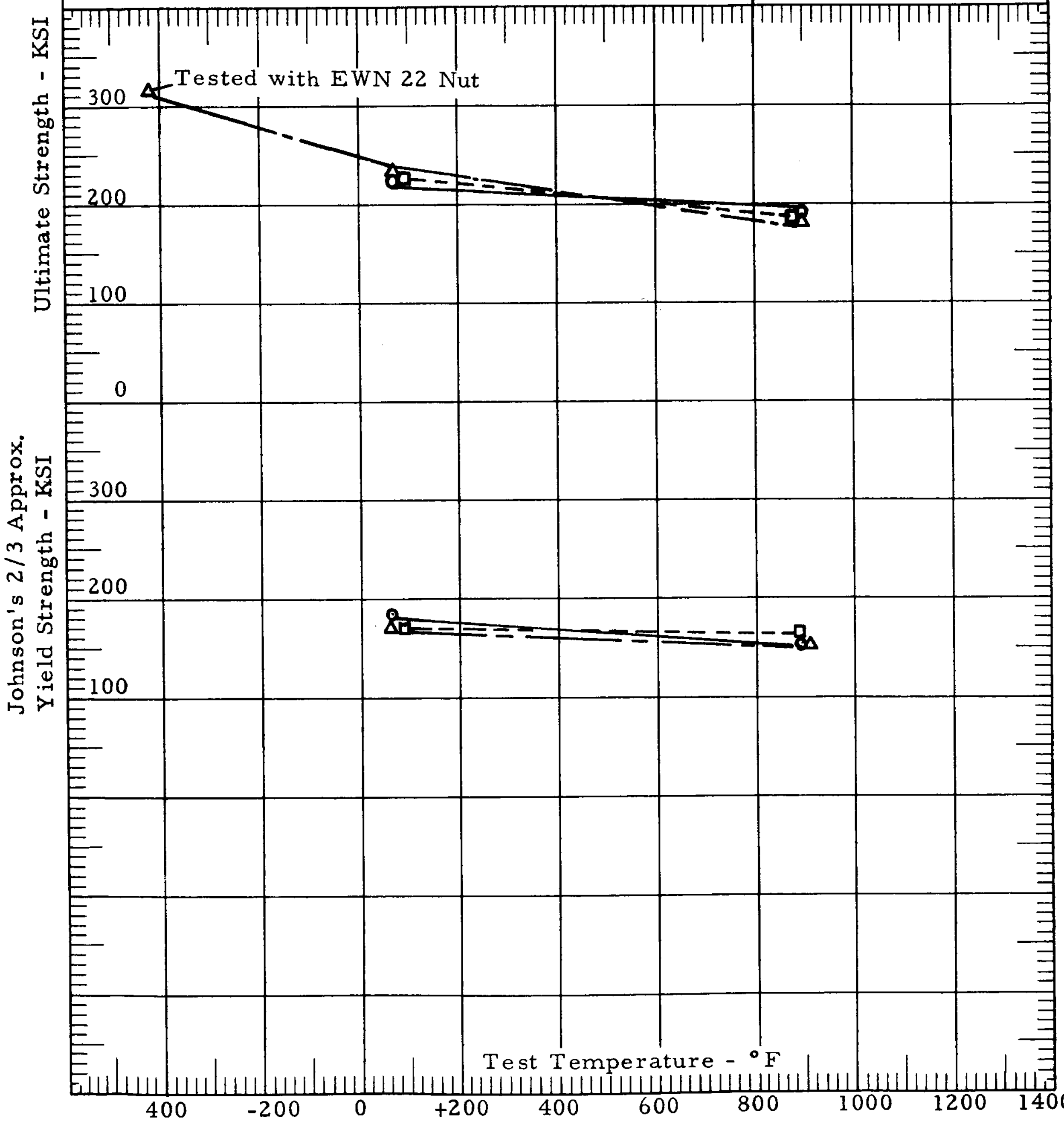
MATERIAL PROPERTIES
Tension Bolt - EWB TM 9
Material - AISI H-11 (220 KSI)
Legend
#10-32 (.113 Spec.)
1/4-28 (.113 Spec.)
1/2-20 (.357 Spec.)
Avg. of 3 Tests
Chart No.: 12
Date:
Ultimate Strength - KSI
300
200
100
0.2% Offset
Yield Strength - KSI
300
200
100
30
Gage Length
.113 Spec. 0.5 inches
.357 Spec. 1.4 inches
20
10
Elongation - %
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3

BOLT & COMPANION NUT PROPERTIES

Bolt - EWBTM9 - Material - H-11 (220 KSI)
Nut - FN922 - Material - H-11 (220 KSI)

Legend
#10-32
1/4-28
1/2-20
Stress calculated at basic pitch diameter
Avg. of 3 Tests

Chart No.: 13
Date:



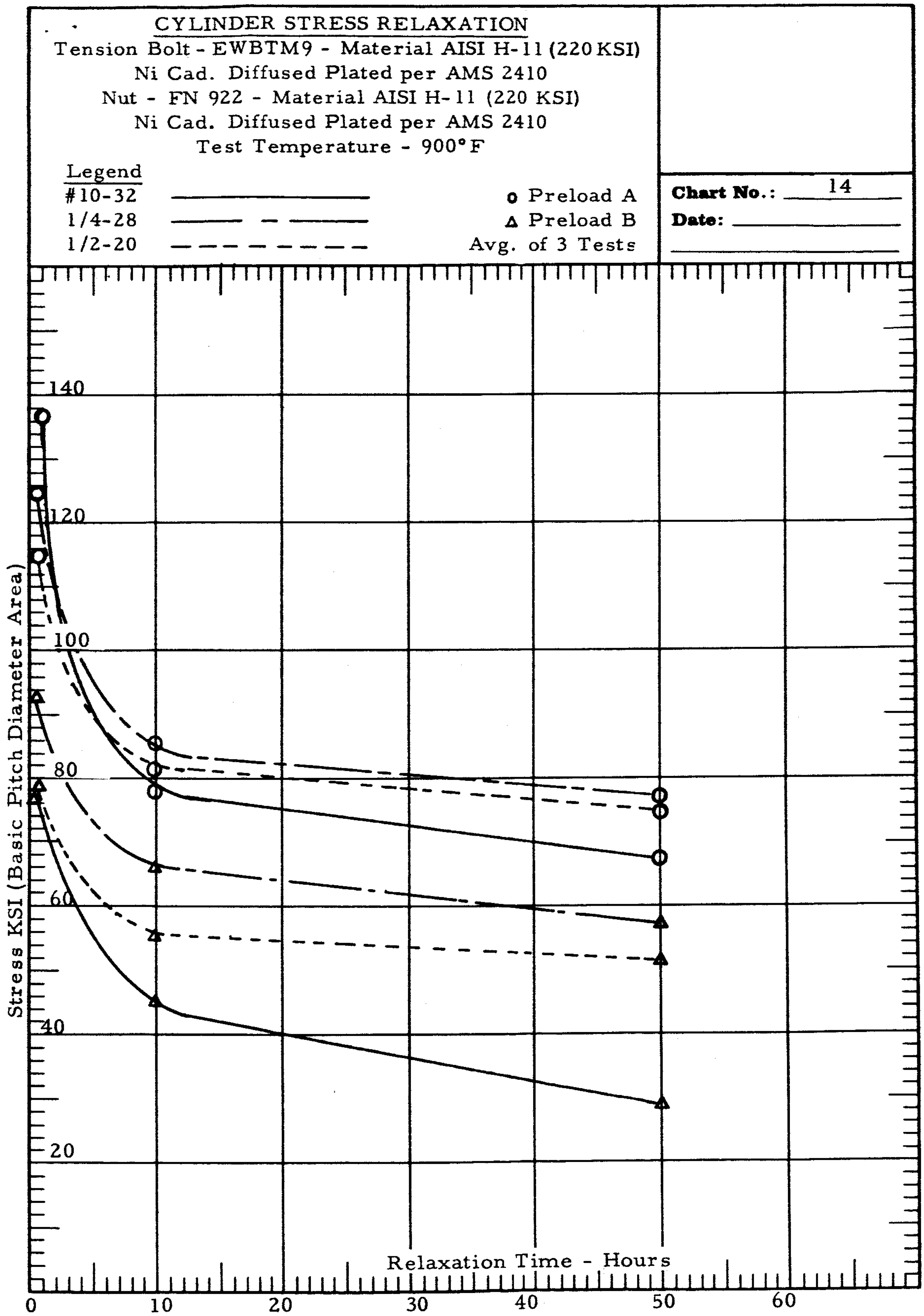

CYLINDER STRESS RELAXATION
Tension Bolt - EWBTM9 - Material AISI H-11 (220 KSI)
Ni Cad. Diffused Plated per AMS 2410
Nut - FN 922 - Material AISI H-11 (220 KSI)
Ni Cad. Diffused Plated per AMS 2410
Test Temperature - 900°F
Legend
#10-32
1/4-28
1/2-20
o Preload A
Δ Preload B
Avg. of 3 Tests
Chart No.: 14
Date:
140
120
100
80
60
40
20
Stress KSI (Basic Pitch Diameter Area)
Relaxation Time - Hours
0
10
20
30
40
50
60

TABLE II

MECHANICAL PROPERTIES

Part No. Bolt - EWB TM 9-3-26 - Material - AISI H-11 (220, ksi)
Part No. Nut - FN 922-1032 - Material - AISI H-11 (220 ksi)
Size - #10-32

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	354,800	No Yield	Specimens Fractured Outside Gage	
2	-423	363,600	No Yield		
3	-423	295,500	No Yield		
4	70	240,900	221,500	10.0	51.3
5	70	248,100	240,700	10.0	48.8
6	70	238,300	229,600	10.0	51.6
7	900	178,500	166,800	16.0	59.7
8	900	179,500	175,700	14.0	64.3
9	900	177,800	171,000	14.0	64.0

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	5,450 (N.C.)	251,200	No Yield	
11	-423	5,320 (N.C.)	245,200	No Yield	
12	-423	4,450 (N.C.)	205,100	No Yield	
13*	-423	7,220	332,700	No Yield	
14*	-423	7,350	338,700	No Yield	
15*	-423	7,200	331,800	No Yield	
16	70	5,100	235,000	4,450	205,100
17	70	5,080	234,100	3,900	179,700
18	70	5,030	231,800	3,900	179,700
19	900	4,340	200,000	3,600	165,900
20	900	4,250 (N.S.)	195,800	3,200	147,500
21	900	4,275 (N.S.)	197,000	3,250	149,800

N.C. - Nut Cracked
N.S. - Nut Stripped

*Tested with Threaded Adapter

(1) Stress calculated at Basic Pitch dia. area of .0217 square inches.

TABLE II (continued)

Part No. EWB TM 9-3-26
FN 922-1032

1. Tensile (continued)-

Base Material Properties (As cycled)
.113 Specimens
Cycled 12 Times
Seated at 115,000 PSI

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong Gage, .5 in. %	Red. of Area, %
22	70	237,400	201,600	13.0	54.3
23	70	242,300	201,500	12.0	58.7
24	70	239,800	200,000	12.0	39.7

70° to 900°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong Gage, .5 in. %	Red. of Area, %
25 (a)	70	240,800	223,100	12.0	46.0
26 (a)	70	244,000	224,700	12.0	50.0
27 (a)	70	242,100	227,300	14.0	52.0
28 (b)	70	237,200	211,200	12.0	50.4

Bolt & Nut Properties
(As Cycled)

70° to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
29	70	5,200 (N.S.)	239,600	4,050	186,600
30	70	5,180 (N.S.)	238,700	4,160	191,700
31	70	5,180 (N.S.)	238,700	4,080	188,000

70°F to 900°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
32 (a)	70	5,190	239,200	4,300	198,100
33 (a)	70	5,070 (N.S.)	233,600	4,000	184,300
34 (a)	70	5,200	239,600	4,150	191,200
35 (b)	70	5,100 (N.S.)	235,000	4,150	191,200
36 (b)	70	5,200	239,600	4,200	193,500

(a) slow cycle
(b) fast cycle

TABLE II (continued)

Part No. EWB TM 9-3-26
FN 922-1032

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
37	70	5,100 (N.S.)	235,000	4,370	201,300
38	70	5,200 (N.S.)	239,600	4,420	203,600
39	70	4,970 (N.S.)	229,000	4,350	200,400

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
40	70	4,920 (N.S.)	226,700	3,920	180,600
41	70	5,000 (N.S.)	230,000	4,160	191,700
42	70	4,930 (N.S.)	227,100	4,110	189,400

2. Double Shear -

(As Received)

Test No.	Test Temp, °F	Ult. Load pounds	Ult. Stress, psi(2)
43	-423	12,000	211,600
44	-423	11,700	206,300
45	-423	11,400	201,000
46	70	7,820	137,900
47	70	7,800	137,500
48	70	7,880	138,900
49	900	6,000	105,800
50	900	6,150	108,400
51	900	6,375	112,400

TABLE II (continued)

Part No. EWB TM 9-3-26
FN 922-1032

2. Double Shear (continued) -

(As Cycled)

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load pounds	Ult. Stress psi(2)
52	70	7,800	137,500
53	70	7,850	138,400
54	70	7,840	138,200
70°F to 900°F to 70°F			
55	70	7,850	138,400
56	70	7,890	139,100
57	70	8,000	141,000
		(As Relaxed - 50 hours)	
Preload A			
58	70	8,000	141,000
59	70	7,900	140,500
60	70	8,000	141,000
Preload B			
61	70	7,620	134,400
62	70	7,600	134,000
63	70	7,720	136,100

3. Stress Rupture

Stress rupture tests at 900°F were not conducted. Fastener assembly is not considered rupture sensitive as evidenced by 1/4 inch results which show the stress required for 100 hour life is 95 percent of the 900°F yield strength.

(2) Stress calculated at twice nominal dia. area, .05671 square inches.

TABLE II (continued)

Part No. EWB TM 9-3-26
FN 922-1032

4. Stress Relaxation @900° F

Preload A - Initial Stress - 124,500 psi

Test No.	Hours Run	Residual Stress pounds	psi[1]
64	10	1699	78,300
65	10	1649	76,000
66	10	1699	78,300
67	50	1519	70,000
68	50	1339	61,700
69	50	1519	70,000

Preload B - Initial Stress - 77,900 psi

Test No.	Hours Run	Residual Stress pounds	psi[1]
70	10	978	45,100
71	10	875	40,300
72	10	977	45,000
73	50	571	26,300
74	50	620	28,600
75	50	660	30,400

TABLE II (continued)

Part No. EWB TM 9-3-26
Nut - FN 922-1032

5. Nut Reuse and Galling Tendency

After Soak @ 70°F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
76	6	118,800	80	58	4
77	11	118,800	85	60	8
78	4	118,000	85	62	3
79	9	118,800	85	63	6
80	5	118,000	80	55	4
2nd Application					
76	4	118,000	75	55	4
77	6	118,800	83	60	7
78	3	118,800	80	58	3
79	5	118,800	85	60	6
80	4	118,800	85	60	3
3rd Application					
76	4	118,800	80	55	4
77	6	118,800	85	60	7
78	3	118,800	85	60	3
79	5	118,800	80	60	5
80	3	118,800	80	58	3
4th Application					
76	4	118,800	83	55	4
77	6	118,800	88	65	7
78	3	118,800	87	65	3
79	3	118,800	80	55	5
80	3	118,800	80	55	3
5th Application					
76	4	118,800	82	55	4
77	6	118,800	85	65	7
78	3	118,800	88	65	3
79	5	118,800	80	58	6
80	3	118,800	83	60	3

TABLE II (continued)

Part No. EWB TM 9-3-26
Nut - FN 922-1032

5. Nut Reuse and Galling Tendency (continued)-

After Soak @ 900° F

Test No.	Maximum Installation, inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
81	9	118,800	85	210	12
82	10	118,800	88	190	13
83	6	118,800	86	160	12
84	5	118,800	85	175	12
85	8	118,800	85	210	10
2nd Application					
81	12	118,800	200	250	10
82	14	118,800	225	210	15
83	11	118,800	200	200	10
84	12	118,800	200	180	11
85	11	118,800	200	175	9
3rd Application					
81	9	118,800	195	225	6
82	14	118,800	200	205	10
83	12	118,800	200	220	8
84	8	118,800	205	220	7
85	13	118,800	195	215	7
4th Application					
81	8	118,800	195	200	4
82	11	118,800	190	210	9
83	10	118,800	190	210	8
84	11	118,800	185	225	6
85	8	118,800	190	190	7
5th Application					
81	5	118,800	225	230	2
82	12	118,800	210	215	8
83	8	118,800	225	220	7
84	9	118,800	190	225	3
85	10	118,800	225	205	7

TABLE II (continued)

Part No. EWB TM 9-3-26
Nut - FN 922-1032

6. Torque vs. Induced Load @ Room Temperature -

Torque, inch-pounds	Test No. 86 Load, pounds	Test No. 87 Load, pounds	Test No. 88 Load, pounds
30	750	1000	1000
40	1050	1300	1250
50	1300	1650	1550
60	1600	2000	1950
70	1900	2250	2250
80	2200	2550	2650
90	2500	2950	3050
100	2850	3300	3350
110	3350	3650	3650
120	3700	3950	3950
130	4000	4100	4100
140	4100	4250	4200
	Bolt Broke	Bolt Broke	Bolt Broke

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
89	14	5	30	30,000	30	No cracks	Passed
90	15	8	30	30,000	10	No cracks	Passed
91	14	5	30	30,000	0	No cracks	Passed
92	9	6	30	30,000	90	No cracks	Passed
93	10	9	30	30,000	0	No cracks	Passed

(1) Stress calculated at Basic P.D. of .0217 square inches.

(2) Stress calculated at twice nominal diameter area, .05671 square inches.

TABLE III

MECHANICAL PROPERTIES

Part No. Bolt - EWB TM 9-4-28 - Material - AISI H-11 (220 ksi)
Part No. Nut FN 922-428 Material - AISI H-11 (220 ksi)
Size - 1/4-28

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
1	-423	343,200	322,100	2.0	5.4
2	-423	350,500	331,600	2.0	5.4
3	-423	249,000	No Yield	-	-
4	70	244,700	239,500	10.0	53.0
5	70	247,400	229,500	10.0	50.4
6	70	244,800	227,000	10.0	51.4
7	900	181,000	172,500	18.0	64.8
8	900	186,800	173,000	16.0	63.8
9	900	183,600	170,400	16.0	63.6

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	5,200 (N.S.)	134,000	No Yield	
11	-423	4,160 (N.S.)	107,200	No Yield	
*12	-423	12,600	322,500	No Yield	
*13	-423	12,200	310,400	No Yield	
15	70	9,150	235,800	7,000	180,400
16	70	9,120	235,000	6,980	179,900
17	70	9,020	232,500	7,000	180,400
18	900	6,900	177,800	6,025	155,200
19	900	6,900	177,800	5,815	151,400
20	900	7,000	180,400	5,900	152,000

(1) Stress calculated at Basic Pitch dia. of .0388 square inches.
(N.S.) Nut Stripped
*Tested with EWN TM9 Nut

TABLE III (continued)

Part No. EWB TM 9-4-28
FN 922-428

1. Tensile (continued) -

Bolt & Nut Properties
(As Relaxed - 50 Hours)

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
21	70	9,250	238,400	7,725	199,100
22	70	9,120	235,100	7,500	193,300
23	70	9,320	240,200	7,725	199,100
Preload B					
24	70	9,460	243,800	7,675	197,800
25	70	9,440	243,300	8,200	211,300
26	70	9,280	239,200	7,650	197,200

2. Double Shear -

(As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
27	-423	17,500	178,300
28	-423	17,300	176,200
29	-423	18,000	183,400
30	70	15,300	155,800
31	70	15,400	156,800
32	70	15,400	156,800
33	900	10,000	101,900
34	900	11,000	112,100
35	900	11,200	114,100

(2) Stress calculated at twice nominal dia area, 09817 square inches.

TABLE III (continued)

Part No. EWB TM 9-4-28
FN 922-428

2. Double Shear (continued)-

(As Relaxed - 50 hours)

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
36	70	14,750	150,200
37	70	14,650	149,200
38	70	14,650	149,200

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
39	70	14,900	151,800
40	70	14,800	150,700
41	70	14,900	151,800

3. Stress Rupture

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
42	900	6,208	160,000	9.2	N. S.
43	900	6,014	155,000	70.8	N. S.
44	900	5,820	150,000	95.6	Bolt Thread
45	900	5,820	150,000	118.9	N. S.
46	900	5,820	150,000	43.2	N. S.
47	900	5,820	150,000	69.5	N. S.

TABLE III (continued)

Part No. EWB TM 9-4-28
FN 922-428

4. Stress Relaxation @ 900°F -

Preload A - Initial Stress - 137,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi(1)
48	10	3,298	85,000
49	10	3,200	82,500
50	10	3,251	83,800
51	50	2,774	71,500
52	50	3,150	81,200
53	50	2,988	77,000

Preload B - Initial Stress - 91,400 psi

54	10	2,502	64,500
55	10	2,553	65,800
56	10	2,553	65,800
57	50	2,200	56,700
58	50	2,200	56,700
59	50	2,200	56,700

TABLE III (continued)

Part No. EWB TM 9-4-28
FN 922-428

5. Nut Reuse and Galling Tendency

After Soak @ -423°F

Test No.	Maximum Installation, inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
60	30	118,800	175	140	20
61	30	118,800	180	150	22
62	30	118,800	180	150	26
63	30	118,800	180	150	22
64	25	118,800	180	140	16
2nd Application					
60	12	118,800	165	120	15
61	20	118,800	170	130	23
62	17	118,800	190	130	20
63	28	118,800	180	130	21
64	12	118,800	175	130	14
3rd Application					
60	14	118,800	170	130	15
61	25	118,800	175	150	25
62	16	118,800	180	130	22
63	14	118,800	180	140	18
64	11	118,800	170	145	14
4th Application					
60	14	118,800	170	110	15
61	20	118,800	175	125	22
62	18	118,800	185	120	22
63	18	118,800	175	120	20
64	12	118,800	180	120	14
5th Application					
60	12	118,800	175	125	15
61	16	118,800	180	140	22
62	16	118,800	185	130	19
63	24	118,800	180	130	16
64	12	118,800	170	150	13

TABLE III (continued)

Part No. EWB TM 9-4-28
Nut - FN 922-428

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 70°F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi (1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
65	30	118,800	150	105	25
66	28	118,800	170	125	28
67	28	118,800	170	115	25
68	28	118,800	180	135	20
69	30	118,800	160	110	23
2nd Application					
65	18	118,800	140	90	20
66	25	118,800	160	110	23
67	23	118,800	150	100	22
68	19	118,800	155	110	15
69	17	118,800	140	90	18
3rd Application					
65	19	118,800	140	100	18
66	25	118,800	150	110	19
67	20	118,800	135	95	20
68	15	118,800	150	105	16
69	15	118,800	135	95	16
4th Application					
65	20	118,800	145	110	16
66	25	118,800	155	120	20
67	22	118,800	130	100	20
68	18	118,800	150	110	16
69	17	118,800	145	105	16
5th Application					
65	20	118,800	165	120	16
66	24	118,800	175	135	18
67	20	118,800	135	100	20
68	19	118,800	155	120	15
69	15	118,800	150	110	16

TABLE III (continued)

Part No. EWB TM 9-4-28
Nut - FN 922-428

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 900°F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
70	30	118,800	150	450	55
71	25	118,800	165	450	60
72	28	118,800	150	450	50
73	28	118,800	170	450	55
74	30	118,800	155	475	50
2nd Application					
70	35	118,800	475	525	50
71	30	118,800	490	450	55
72	30	118,800	480	550	60
73	28	118,800	485	450	55
74	35	118,800	480	500	55
3rd Application					
70	30	118,800	475	500	45
71	30	118,800	480	525	50
72	25	118,800	480	500	45
73	20	118,800	485	525	50
74	35	118,800	475	500	40
4th Application					
70	25	118,800	500	550	30
71	20	118,800	520	575	35
72	25	118,800	525	550	40
73	20	118,800	500	575	55
74	30	118,800	500	550	50
5th Application					
70	20	118,800	550	600	40
71	25	118,800	590	620	30
72	20	118,800	575	600	25
73	18	118,800	575	590	50
74	25	118,800	575	600	35

TABLE III (continued)

Part No. EWB TM 9-4-28
Nut - FN 922-428

6. Torque Versus Induced Load -

Torque, inch-pounds	Test No. 75 Load, pounds	Test No. 76 Load, pounds	Test No. 77 Load, pounds
50	700	500	1100
100	2050	2300	2950
150	3350	3850	4850
200	4850	5250	5850
250	6400	7500	7750
300	7700	8050	8250

7. Vibration - ALMA #10 -

Test No.	Maximum Installation inch, pounds 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp	Remarks
78	30	15	60	30,000	30	No cracks	Passed
79	28	15	60	30,000	30	No cracks	Passed
80	30	15	60	30,000	30	No cracks	Passed
81	24	18	60	30,000	45	No cracks	Passed
82	27	20	60	30,000	60	No cracks	Passed

(1) Stress calculated at basic P. D. area of .0388 square inches.

(2) Stress calculated at twice nominal diameter area, .09817 square inches.

TABLE IV

MECHANICAL PROPERTIES

Part No. Bolt - EWB TM 9-8-46 - Material - AISI H-11 (220 ksi)
Part No. - Nut - FN 922-820 - Material - AISI H-11 (220 ksi)
Size - 1/2-20x3.781

1. Tensile - Base Material Properties (As Received)
.357 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress psi	Elong, Gage, 1.4 in. %	Red. of Area, %
1	-423	220,400	No Yield	-	2.2
2	-423	271,400	No Yield	-	1.1
3	-423	226,100	No Yield	-	1.1
4	70	242,700	211,000	14.2	48.3
5	70	246,200	214,000	14.2	47.4
6	70	241,300	209,000	12.8	46.0
7	900	178,500	170,000	15.7	61.3
8	900	175,500	165,000	17.1	64.7
9	900	Specimen overheated during test.			

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	19,000 (N. C.)	111,000	No Yield	
11	-423	25,300 (N. C.)	147,200	No Yield	
*12	-423	30,800 (H)	179,500	No Yield	
15	70	40,000 (N. S.)	233,100	31,000	180,600
16	70	38,500 (N. S.	224,300	30,500	177,700
17	70	39,800 (N. S.)	231,900	30,500	177,700
18	900	31,600 (N. S.)	184,000	27,750	161,700
19	900	32,000 (N. S.)	186,500	27,500	160,000
20	900	33,200 (N. S.)	193,500	28,500	166,000

(1) Stress calculated at Basic Pitch dia. area of .1716 square inches.
N. C. - Nut Cracked.
N. S. - Nut Stripped.
H - Head Failure
*Tested with EWN TM9 Nut

TABLE IV (continued)

Part No. EWB TM 9-8-46
FN 922-820

1. Tensile (continued) -

Base Material Properties (As Cycled)
.357 Specimens
Cycled 12 times
Seated at 115,000 psi

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
70°F to 900°F to 70°F					
21	70	245,000	217,000	12.8	49.6
22	70	238,900	204,000	12.8	44.5
23	70	Specimen damaged -- not tested.			

Bolt & Nut Properties
(As Cycled)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
24	70	41,600	242,400	35,000	203,900
25	70	41,100	239,500	34,600	201,600
26	70	41,400	241,200	34,000	198,100
As Relaxed - 50 Hours					
Preload A					
27	70	40,500	236,000	32,500	189,300
28	70	40,700	237,100	33,400	194,600
29	70	40,600	236,500	33,000	194,000
Preload B					
30	70	41,200(N.S.)	240,100	32,000	186,500
31	70	41,000	238,900	32,400	188,800
32	70	40,500	236,000	31,200	181,800

N. S. Nut Stripped.

TABLE IV (continued)

Part No. EWB TM 9-8-46
FN 922-820

2. Double Shear -

(As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
33	-423	Shear Fixture Failed	
34	-423	Shear Fixture Failed	
35	-423	Stud in Cryostat Failed	
36	70	58,000	147,700
37	70	56,500	143,900
38	70	58,200	148,200
39	900	44,700	114,000
40	900	45,200	115,200
41	900	45,000	115,000
		(As Cycled)	
70°F to 900°F to 70°F			
42	70	60,500	154,100
43	70	61,000	155,300
44	70	61,400	156,400
		(As Relaxed - 50 Hours)	
Preload A			
45	70	58,000	147,700
46	70	58,600	149,200
47	70	59,600	151,800
Preload B			
48	70	57,100	145,400
49	70	58,000	147,700
50	70	59,000	150,200

3. Stress Rupture -

Stress rupture tests at 900°F were not conducted. Fastener assembly is not considered rupture sensitive as evidenced by 1/4 inch results which show the stress required for 100 hour life is 95 percent of the 900°F yield strength.

TABLE IV (continued)

Part No. EWB TM 9-8-46
FN 922-820

4. Stress Relaxation @900°F

Preload A - Initial Stress 115,500 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi(1)
51	10	14,190	82,700
52	10	13,900	81,000
53	10	13,900	81,000
54	50	13,280	77,400
55	50	12,800	74,600
56	50	12,715	74,100

Preload B - Initial Stress - 78,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi(1)
57	10	9,590	55,900
58	10	9,385	54,700
59	10	9,385	54,700
60	50	9,000	52,500
61	50	8,685	50,600
62	50	8,800	51,300

TABLE IV (continued)

Part No. EWB TM 9-8-46
Nut - FN 922-820

5. Nut Reuse and Galling Tendency

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
63	90	118,800	1150	750	77
64	80	118,800	975	600	60
65	100	118,800	1150	750	60
66	90	118,800	900	500	59
67	90	118,800	950	575	68
2nd Application					
63	72	118,800	1150	775	68
64	64	118,800	950	650	63
65	64	118,800	1200	825	56
66	64	118,800	950	575	64
67	64	118,800	925	600	58
3rd Application					
63	72	118,800	1150	900	70
64	64	118,800	975	775	60
65	52	118,800	1225	1000	50
66	58	118,800	975	775	60
67	63	118,800	900	750	60
4th Application					
63	70	118,800	1200	950	60
64	70	118,800	1200	900	60
65	50	118,800	1320	1100	50
66	60	118,800	1100	900	55
67	78	118,800	1000	750	60
5th Application					
63	70	118,800	1200	1000	60
64	70	118,800	1200	1050	50
65	50	118,800	1320	1200	40
66	60	118,800	1200	1000	50
67	60	118,800	1000	900	45

TABLE IV (continued)

Part No. EWB TM 9-8-46
Nut - FN 922-820

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 900°F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
68	90	118,800	950	2160	125
69	85	118,800	900	2880	140
70	100	118,800	1100	2280	125
71	90	118,800	1000	2220	150
72	95	118,800	1200	2160	100
2nd Application					
68	145	118,800	3000	3120	100
69	155	118,800	3000	3000	125
70	170	118,800	2640	2880	100
71	165	118,800	2640	3120	120
72	80	118,800	2280	2880	50
3rd Application					
68	110	118,800	3000	3480	80
69	125	118,800	3480	3360	110
70	140	118,800	3480	3600	90
71	120	118,800	3360	3360	115
72	50	118,800	3480	3600	40
4th Application					
68	65	118,800	3480	3600	65
69	120	118,800	3800	4000	100
70	140	118,800	3800	4200	80
71	120	118,800	3900	4000	110
72	50	118,800	3600	3800	60
5th Application					
68	70	118,800	3800	4000	55
69	120	118,800	3600	3800	95
70	80	118,800	3900	4200	75
71	100	118,800	3800	4000	110
72	60	118,800	3600	3800	50

TABLE IV (continued)

Part No. EWB TM 9-8-46
Nut - FN 922-820

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 73 Load, pounds	Test No. 74 Load, pounds	Test No. 75 Load, pounds
400	7,000	6,000	6,500
800	14,500	14,000	16,500
1200	21,600	20,500	22,000
1600	28,000	31,000	31,000
2000	32,500	33,500	33,000

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
76	100	75	300	30,000	0	No cracks	Passed
77	100	50	300	30,000	0	No cracks	Passed
78	125	80	300	30,000	0	No cracks	Passed
79	125	100	300	30,000	0	No cracks	Passed
80	125	75	300	30,000	0	No cracks	Passed

(1) Stress calculated at Basic P.D. area of .1716 square inches.

(2) Stress calculated at twice nominal diameter area, .3927 square inches.

TABLE V

SUMMARY OF RESULTS

EWB 1615 & FN 1418 - MATERIAL - WASPALOY - (150 KSI)

Material Properties -

Test Temp.	U. T. S.- KSI #10	U. T. S.- KSI 1/4	U. T. S.- KSI 1/2	0.2% Offset Yield - KSI #10	0.2% Offset Yield - KSI 1/4	0.2% Offset Yield - KSI 1/2	Elongation - % #10	Elongation - % 1/4	Elongation - % 1/2
-423°F	283.9	245.3	216.1	209.7	173.7	158.3	14.0	20.0	10.7
	256.0	247.4	220.4	186.8	192.1	149.1	14.0	20.0	12.8
	242.1	238.7	219.5	205.3	188.2	148.4	14.0	18.0	19.3
70°F	193.8	193.5	185.0	143.8	134.4	123.8	16.0	20.0	17.8
	196.8	191.5	187.5	139.5	129.4	126.3	18.0	20.0	18.5
	193.8	191.5	184.4	137.7	130.5	123.1	16.0	20.0	18.5
1400°F	136.0	139.7	133.6	110.0	109.6	109.0	8.0	12.0	14.2
	134.9	136.4	112.5	109.2	111.4	98.0	12.0	14.3	12.8
	140.8	140.6	113.5	107.1	114.5	97.4	12.0	14.3	11.4

Test Temp.	Reduction of Area - % #10	Reduction of Area - % 1/4	Reduction of Area - % 1/2	Shear Strength - KSI #10	Shear Strength - KSI 1/4	Shear Strength - KSI 1/2
-423°F	14.5	19.0	14.0	176.3	157.9	
	14.0	20.6	16.2	172.8	154.8	
	14.0	20.8	20.8	174.6	156.9	
70°F	20.0	31.9	29.8	132.6	132.4	121.0
	22.0	30.0	20.8	136.5	132.4	126.1
	21.9	30.0	20.7	136.7	132.4	126.8
1400°F	11.0	15.3	23.7	92.0	85.6	88.5
	18.4	17.5	21.6	97.4	89.6	91.0
	10.2	16.2	18.3	97.0	94.7	89.6

Bolt & Nut Properties -

Test Temp.	U.T.S. - KSI (1) #10	U.T.S. - KSI (1) 1/4	U.T.S. - KSI (1) 1/2	Johnson's 2/3 Approx. Yield - KSI #10	Johnson's 2/3 Approx. Yield - KSI 1/4	Johnson's 2/3 Approx. Yield - KSI 1/2
-423°F	223.4	214.9	201.0	213.0	180.9	155.0
	237.9	220.0	206.2	189.6	176.7	155.0
	241.6	223.4	199.0	192.2	158.3	157.0
70°F	187.0	171.8	167.3	142.8	139.2	126.7
	181.8	172.7	167.9	135.0	135.7	126.0
	180.7	172.4	169.2	135.0	135.7	128.6
1400°F	185.7	163.9	150.1	145.4	125.8	114.0
	194.8	144.1	153.9	140.2	134.2	117.2
	185.7	159.7	156.5	145.4	124.3	117.2

(1) Stress calculated at tensile stress area (.003 red pitch diameter)

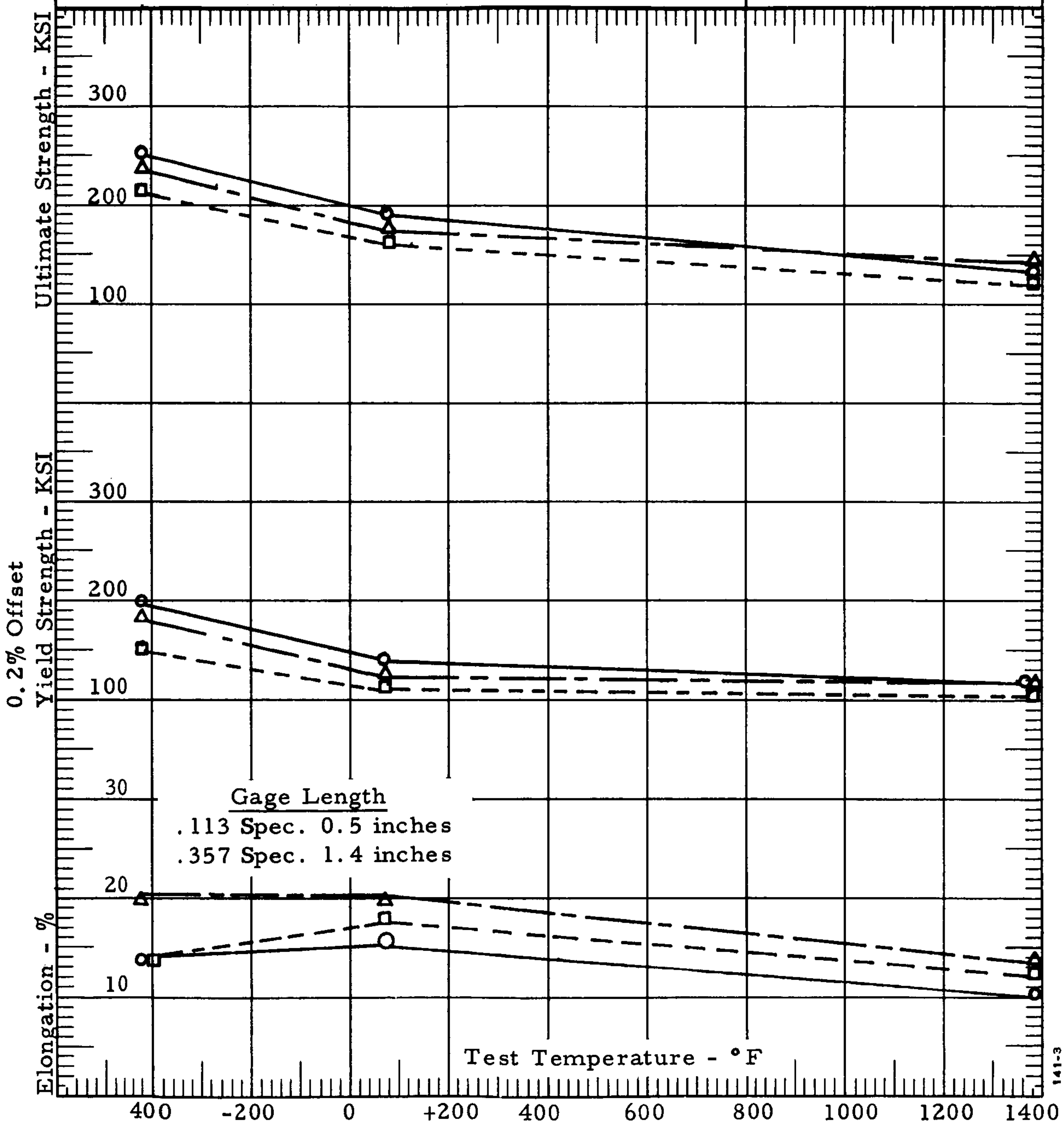
MATERIAL PROPERTIES

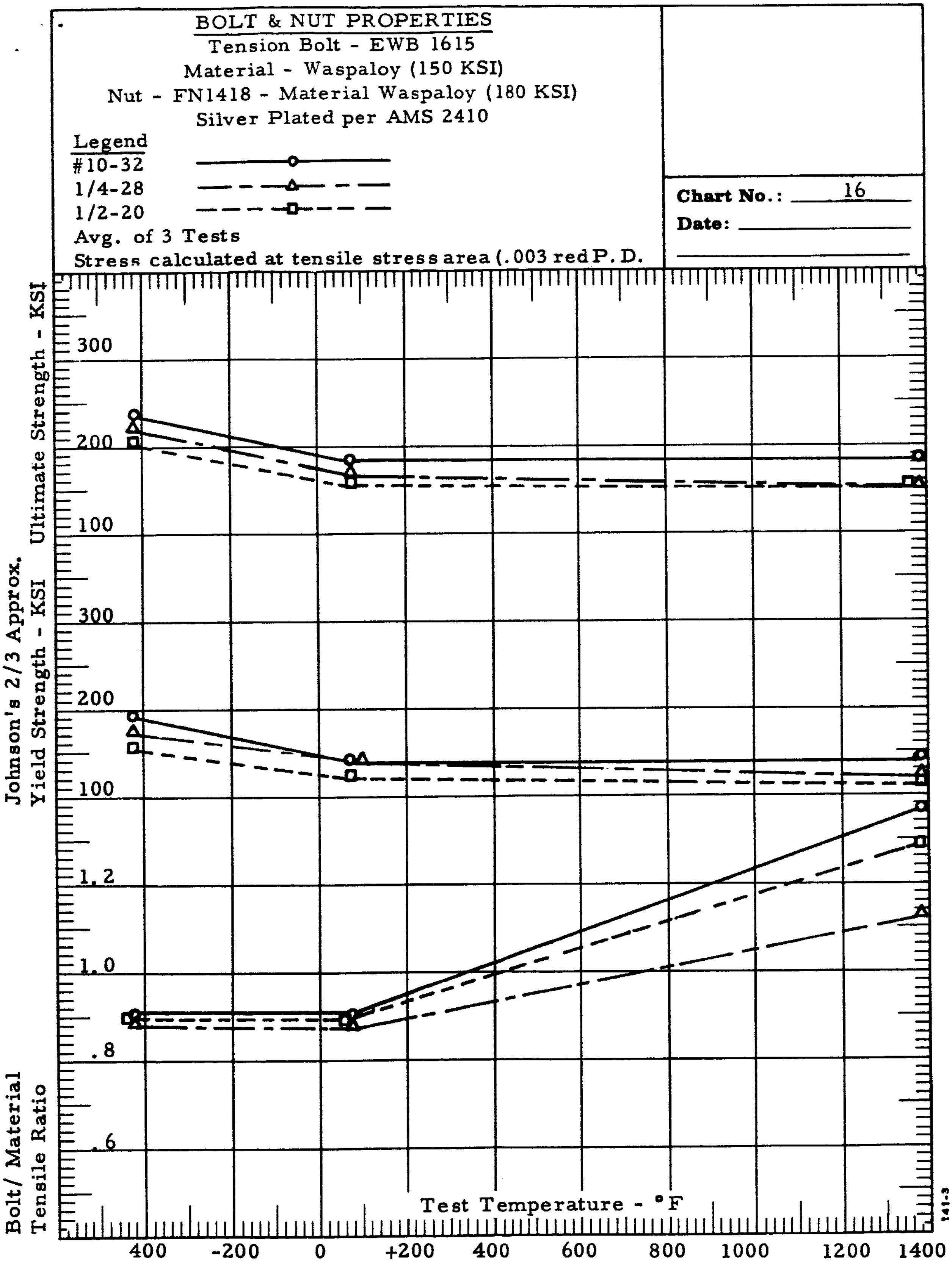
Tension Bolt - EWB 1615
Material - Waspaloy (150 KSI)

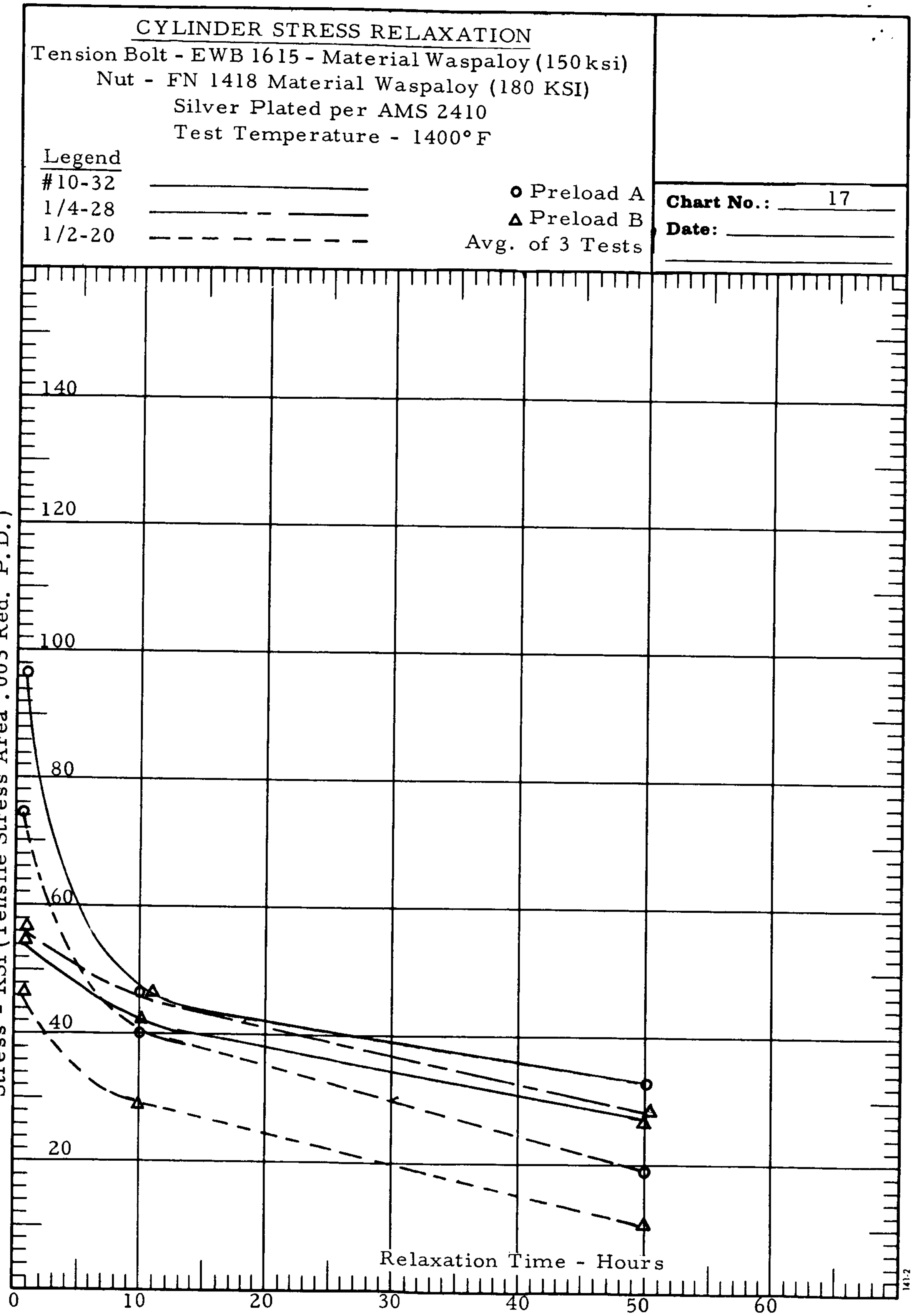
Legend
#10 (.113 Spec.) ——o——
1/4 (.113 Spec.) — — △— —
1/2 (.357 Spec.) - - -□- - -

Avg. of 3 Tests

Chart No.: 15
Date:




BOLT & NUT PROPERTIES
Tension Bolt - EWB 1615
Material - Waspaloy (150 KSI)
Nut - FN1418 - Material Waspaloy (180 KSI)
Silver Plated per AMS 2410
Legend
#10-32
1/4-28
1/2-20
Avg. of 3 Tests
Stress calculated at tensile stress area (.003 red P. D.
Chart No.: 16
Date:
Ultimate Strength - KSI
Johnson's 2/3 Approx. Yield Strength - KSI
Bolt/ Material Tensile Ratio
300
200
100
300
200
100
1.2
1.0
.8
.6
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3


CYLINDER STRESS RELAXATION
Tension Bolt - EWB 1615 - Material Waspaloy (150 ksi)
Nut - FN 1418 Material Waspaloy (180 KSI)
Silver Plated per AMS 2410
Test Temperature - 1400° F
Legend
#10-32
1/4-28
1/2-20
o Preload A
Δ Preload B
Avg. of 3 Tests
Chart No.: 17
Date:
Stress - KSI (Tensile Stress Area .003 Red. P.D.)
140
120
100
80
60
40
20
Relaxation Time - Hours
0
10
20
30
40
50
60

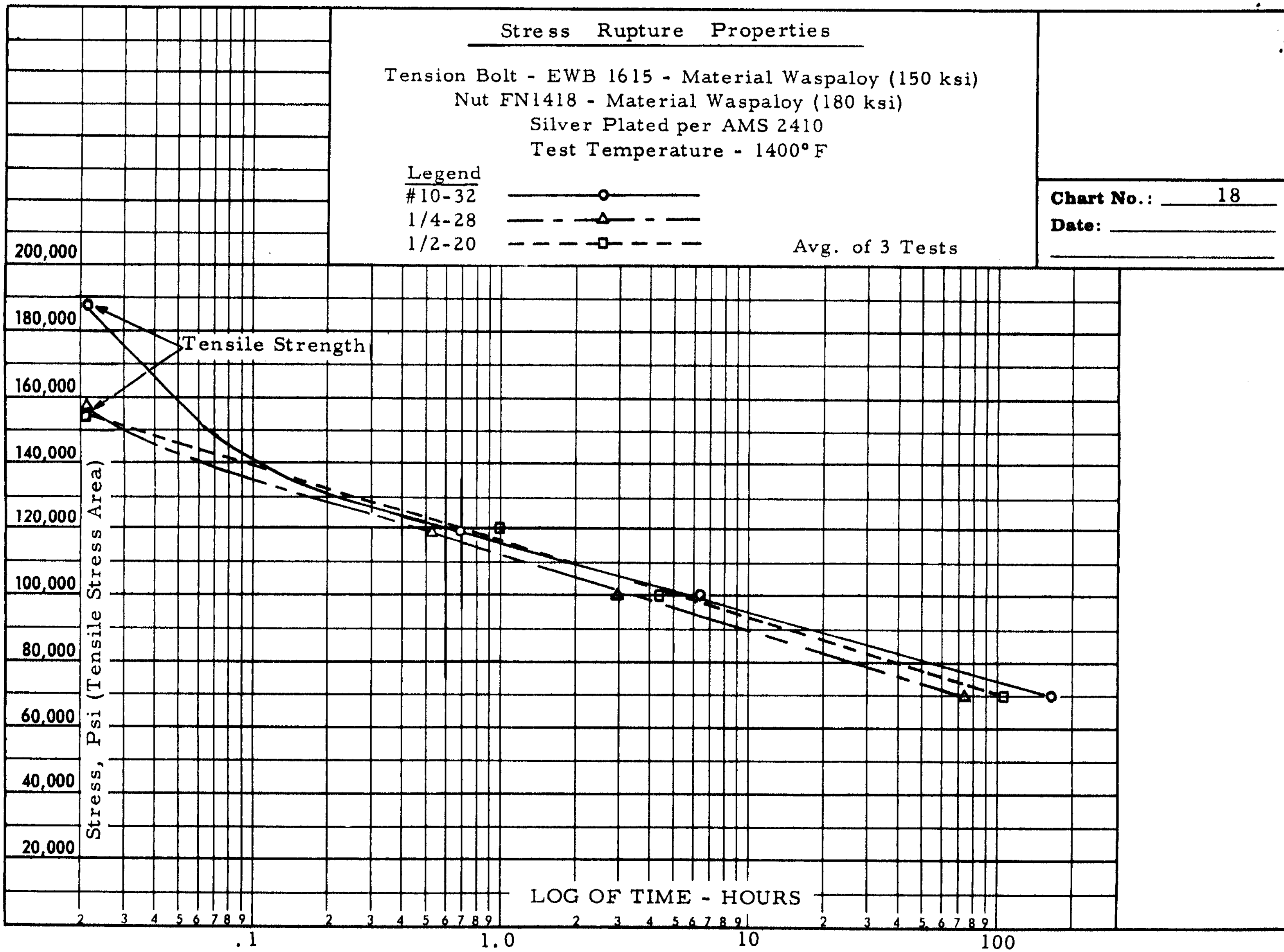

Stress Rupture Properties
Tension Bolt - EWB 1615 - Material Waspaloy (150 ksi)
Nut FN1418 - Material Waspaloy (180 ksi)
Silver Plated per AMS 2410
Test Temperature - 1400° F
Legend
#10-32
1/4-28
1/2-20
Avg. of 3 Tests
Chart No.: 18
Date:
Tensile Strength
Stress, Psi (Tensile Stress Area)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
LOG OF TIME - HOURS
.1
1.0
10
100
141-6

TABLE VI

MECHANICAL PROPERTIES

Part No. Bolt EWB 1615-3-34 - Material Waspaloy (150 ksi)
Part No. Nut - FN 1418-1032 Material - Waspaloy (180 ksi)
Size - #10-32x2. 528

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
1	-423	283,900	209,700	14.0	14.5
2	-423	256,000	186,800	14.0	14.0
3	-423	242,100	205,300	14.0	14.0
4	70	193,800	143,800	16.0	20.0
5	70	196,800	139,500	18.0	22.0
6	70	193,800	137,700	16.0	21.9
7	1400	136,000	110,000	8.0	11.0
8	1400	134,900	109,200	12.0	18.4
9	1400	140,800	107,100	12.0	10.2

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	4,300	223,400	4,100	213,000
11	-423	4,580	237,900	3,650	189,600
12	-423	4,650	241,600	3,700	192,200
13	70	3,600	187,000	2,750	142,800
14	70	3,500	181,800	2,600	135,000
15	70	3,480	180,700	2,600	135,000
16	1400	3,575	185,700	2,800	145,400
17	1400	3,750	194,800	2,700	140,200
18	1400	3,600	187,000	2,700	140,200

(1) Stress calculated at tensile stress area (.003 red pitch dia.), .01925 square inches.

TABLE VI (continued)

Part No. EWB 1615-3-3-34
FN 1418-1032

1. Tensile (continued) -

Base Material Properties (As cycled)
.113 Specimens
Cycled 12 Times
Seated at 83,200 psi

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
19	70	191,300	125,500	9.0	23.4
20	70	192,100	128,400	8.0	23.8
21	70	181,600	123,700	9.0	20.6

70°F to 1400°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
22(a)	70	183,100	115,700	24.0	30.0
23(b)	70	193,500	119,300	24.0	30.5

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
24	70	3,720	193,200	2,770	143,900
25	70	3,620	188,000	2,850	148,100
26	70	3,580	186,000	2,820	146,500

70°F to 1400°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
27 (a)	70	3,550	184,400	2,630	136,600
28 (a)	70	3,600	187,000	2,700	140,300
29 (b)	70	3,550	184,400	2,600	135,100
30 (b)	70	3,530	183,400	2,600	135,100

(a) Fast Cycle
(b) Slow Cycle

TABLE VI (continued)

Part No. EWB 1615-3-34
FN 1418-1032

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
31	70	3,920	203,600	2,870	149,100
32	70	3,880	201,600	2,550	132,500
33	70	3,920	203,600	3,050	158,400

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
34	70	3,850	200,000	2,920	151,700
35	70	3,880	201,600	2,980	154,800
36	70	3,820	198,400	3,160	164,200

2. Double Shear -

As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
37	-423	10,000	176,300
38	-423	9,800	172,800
39	-423	9,900	174,600
40	70	6,400	112,800
41	70	6,920	122,000
42	70	6,800	119,900
43	1400	5,500	97,000
44	1400	5,525	97,400
45	1400	5,500	97,000

TABLE VI (continued)

Part No. EWB 1615-3-34
FN 1418-1032

2. Double Shear (continued) -

(As Cycled)

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
46	70	6,780	119,600
47	70	6,730	118,700
48	70	6,770	119,400

70°F to 1400°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
49 (a)	70	6,550	115,500
50 (a)	70	6,760	119,200
51 (b)	70	6,840	120,600
52 (b)	70	6,820	120,300

(As Relaxed - 50 hours)

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
53	70	7,050	124,300
54	70	6,990	123,300
55	70	7,000	123,400

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
56	70	6,960	124,300
57	70	6,860	123,300
58	70	7,000	123,400

(2) Stress calculated at twice nominal dia., .05671 square inches.

TABLE VI (continued)

Part No. EWB 1615-3-34
FN 1418-1032

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
59	1400	1,348	70,000	101.5	T
60	1400	1,348	70,000	141.5	T
61	1400	1,348	70,000	112.8	T
62	1400	1,925	100,000	4.7	T
63	1400	1,925	100,000	6.5	T
64	1400	1,925	100,000	11.1	T
65	1400	2,310	120,000	0.6	T
66	1400	2,310	120,000	0.7	T
67	1400	2,310	120,000	0.7	T

4. Stress Relaxation @ 1400°F -

Preload A - Initial Stress - 96,500 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
68	10	839	43,600
69	10	950	49,400
70	10		
71	50	504	26,200
72	50	720	37,400
73	50	700	36,400

Preload B - Initial Stress - 54,500 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
74	10	918	47,700
75	10	670	34,800
76	10	839	43,600
77	50	570	29,600
78	50	529	27,500
79	50	479	24,900

TABLE VI (continued)

Part No. EWB 1615-3-34
Nut - FN 1418-1032

5. Nut Reuse and Galling Tendency -

After Soak @ -423° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
80	16	81,000	140	140	6
81	11	81,000	130	100	6
82	12	81,000	125	100	7
83	10	81,000	130	80	7
84	14	81,000	130	100	6
2nd Application					
80	5	81,000	140	140	4
81	5	81,000	135	100	3
82	7	81,000	120	120	6
83	5	81,000	125	120	4
84	5	81,000	125	140	5
3rd Application					
80	3	81,000	135	120	2
81	5	81,000	130	110	3
82	7	81,000	130	120	5
83	5	81,000	125	120	5
84	5	81,000	130	110	4
4th Application					
80	8	81,000	150	150	5
81	12	81,000	130	100	6
82	10	81,000	150	135	6
83	8	81,000	150	140	5
84	10	81,000	160	150	6
5th Application					
80	4	81,000	135	110	2
81	4	81,000	130	90	3
82	5	81,000	125	110	4
83	6	81,000	130	110	4
84	4	81,000	130	85	3

TABLE VI (continued)

Part No. EWB 1615-3-34
Nut - FN 1418-1032

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
85	10	81,000	110	100	7
86	9	81,000	140	135	6
87	10	81,000	110	105	7
88	10	81,000	100	90	6
89	8	81,000	120	120	5
2nd Application					
85	8	81,000	135	130	7
86	7	81,000	145	145	4
87	7	81,000	125	120	9
88	12	81,000	115	95	7
89	8	81,000	130	125	6
3rd Application					
85	15	81,000	140	140	9
86	6	81,000	145	130	6
87	11	81,000	130	120	10
88	10	81,000	120	100	6
89	12	81,000	130	130	8
4th Application					
85	8	81,000	140	130	6
86	10	81,000	140	130	8
87	8	81,000	130	120	8
88	10	81,000	120	100	8
89	9	81,000	125	120	7
5th Application					
85	9	81,000	140	135	8
86	8	81,000	145	135	6
87	8	81,000	135	125	8
88	13	81,000	135	115	10
89	12	81,000	140	135	12

TABLE VI (continued)

Part No. EWB 1615-3-34
Nut - FN 1418-1032

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 1400° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
90	10	81,000	110	290	6
91	11	81,000	90	190	12
92	8	81,000	90	180	10
93	9	81,000	115	160	11
94	8	81,000	130	170	10
2nd Application					
90	8	81,000	170	190	7
91	10	81,000	155	195	10
92	8	81,000	150	180	8
93	9	81,000	180	180	5
94	10	81,000	175	190	3
3rd Application					
90	9	81,000	180	190	9
91	14	81,000	160	195	12
92	6	81,000	160	180	6
93	7	81,000	180	190	3
94	7	81,000	180	185	4
4th Application					
90	11	Bolt broke	--	--	--
91	15	81,000	190	190	10
92	6	81,000	185	185	6
93	7	81,000	190	175	5
94	7	81,000	190	180	4
5th Application					
90	--	--	--	--	--
91	12	81,000	185	Bolt broke	--
92	9	81,000	190	180	9
93	10	Bolt broke	--	--	--
94	8	81,000	195	180	4

TABLE VI (continued)

Part No. EWB 1615-3-34
Nut - FN 1418-1032

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 95 Load, pounds	Test No. 96 Load, pounds	Test No. 97 Load, pounds
30	550	600	650
40	750	850	800
50	1000	1050	1000
60	1300	1250	1150
70	1600	1550	1650
80	1750	1850	1700
90	2000	2050	2000
100	2250	2300	2300
110	2450	2500	2450
120	2750	2800	2750

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
98	10	6	30	30,000	45	No Cracks	Passed
99	8	5	30	30,000	30	No Cracks	Passed
100	9	4	30	30,000	30	No Cracks	Passed
101	8	4	30	30,000	90	No Cracks	Passed
102	11	6	30	30,000	15	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area (.003 Red Pitch Dia.) .01925 square inches.

(2) Stress calculated at twice nominal diameter area, .05671 square inches.

TABLE VII

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-38 - Material - Waspaloy (150 ksi)
Part No. - Nut - FN 1418-428
Size - 1/4-28

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
1	-423	245,300	173,700	20.0	19.0
2	-423	247,400	192,100	20.0	20.6
3	-423	238,700	188,200	18.0	20.8
4	70	193,500	134,400	20.0	31.9
5	70	191,500	129,400	20.0	30.0
6	70	191,500	130,500	20.0	30.0
7	1400	139,700	109,600	12.0	15.3
8	1400	136,400	111,400	14.3	17.5
9	1400	140,600	114,500	14.3	16.2

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	8,000	226,200	6,900	194,100
11	-423	7,700	220,000	6,250	176,700
12	-423	7,900	223,400	5,600	158,300
13	70	6,080	171,800	4,925	139,200
14	70	6,110	172,.700	4,800	135,700
15	70	6,100	172,400	4,800	135,700
16	1400	5,800	163,900	4,450	125,800
17	1400	5,100	144,100	4,750	134,200
18	1400	5,650	159,700	4,400	124,300

(1) Stress calculated at tensile stress area (.003 red pitch dia.), .03537 square inches.

TABLE VII (continued)

Part No. EWB 1615-4-38
FN 922-428

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A - Not Tested

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	70	6,300	178,100	5,000	141,400
20	70	6,340	179,200	5,000	141,400
21	70	6,280	177,600	5,100	144,200

2. Double Shear -

(As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
22	-423	15,500	157,900
23	-423	15,200	154,800
24	-423	15,400	156,900
25	70	13,000	132,400
26	70	13,000	132,400
27	70	13,000	132,400
28	1400	8,400	85,600
29	1400	8,800	89,600
30	1400	9,300	94,700

(As Relaxed - 50 hours)

Preload A - Not Tested

Preload B

31	70	12,950	131,900
32	70	13,100	133,400
33	70	12,950	131,900

(2) Stress calculated at twice nominal dia. area, .09817 square inches.

TABLE VII (continued)

Part No. EWB 1615-4-38
FN 1418-428

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
34	1400	2,476	70,000	96.3	T
35	1400	2,476	70,000	63.7	T
36	1400	2,476	70,000	100.1	T
37	1400	3,527	100,000	4.4	T
38	1400	3,527	100,000	3.5	T
39	1400	3,527	100,000	1.7	T
40	1400	4,242	120,000	.7	T
41	1400	4,242	120,000	.5	T
42	1400	4,242	120,000	.5	T

4. Stress Relaxation @ 1400°F -

Preload A - Initial Stress - 86,400 psi

Preload too high for this fastener system due to nut cracking after installation at room temperature.

Preload B - Initial Stress - 56,500 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
43	10	1,698	48,000
44	10	1,598	45,200
45	10		
46	50	1,025	28,900
47	50	1,025	28,900
48	50	1,075	30,300

TABLE VII (continued)

Part No. EWB 1615-4-38
Nut - FN 1418-428

5. Nut Reuse and Galling Tendency -

After Soak @ -423° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
49	20	81,000	300	240	18
50	23	81,000	275	200	14
51	28	81,000	280	260	20
52	20	81,000	275	240	12
53	20	81,000	265	250	10
2nd Application					
49	22	81,000	295	225	22
50	14	81,000	280	210	13
51	18	81,000	275	240	13
52	16	81,000	270	250	12
53	6	81,000	270	250	6
3rd Application					
49	14	81,000	285	210	8
50	17	81,000	270	225	14
51	12	81,000	275	240	16
52	12	81,000	270	240	12
53	6	81,000	275	230	8
4th Application					
49	22	81,000	295	250	16
50	24	81,000	280	210	12
51	18	81,000	280	260	16
52	10	81,000	275	250	10
53	9	81,000	270	250	8
5th Application					
49	16	81,000	290	225	11
50	16	81,000	275	220	14
51	14	81,000	275	240	15
52	14	81,000	275	250	12
53	7	81,000	275	225	7

TABLE VII (continued)

Part No. EWB 1615-4-38
Nut - FN 1418-428

5. Nut Reuse and Galling Tendency -

After Soak @ 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
54	30	81,000	260	230	22
55	35	81,000	230	210	30
56	30	81,000	240	200	23
57	35	81,000	250	228	25
58	35	81,000	255	210	22
2nd Application					
54	30	81,000	275	275	18
55	28	81,000	250	240	25
56	20	81,000	210	180	20
57	35	81,000	325	300	23
58	23	81,000	275	260	18
3rd Application					
54	28	81,000	275	240	23
55	25	81,000	230	200	15
56	12	81,000	225	190	13
57	30	81,000	325	300	23
58	15	81,000	285	260	13
4th Application					
54	15	81,000	275	Bolt broke	
55	23	81,000	220	160	18
56	15	81,000	220	180	12
57	25	81,000	325	280	20
58	18	81,000	285	260	13
5th Application					
54	--	--	--	--	--
55	20	81,000	210	185	16
56	15	81,000	225	190	11
57	23	81,000	325	295	16
58	15	81,000	275	240	12

TABLE VII (continued)

Part No. EWB 1615-4-38
Nut - FN 1418-428

5. Nut Reuse and Galling Tendency (continued) -

After Soak @1400°F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
59	28	81,000	225	310	30
60	28	81,000	210	390	35
61	33	81,000	200	375	30
62	23	81,000	190	375	23
63	35	81,000	215	400	33
2nd Application					
59	50	81,000	340	350	35
60	35	81,000	375	400	30
61	45	81,000	340	410	33
62	20	81,000	360	400	20
63	35	81,000	380	425	35
3rd Application					
59	40	81,000	325	350	35
60	50	81,000	350	410	40
61	30	81,000	325	410	Galled
62	25	81,000	365	425	30
63	30	81,000	375	425	30
4th Application					
59	30	81,000	300	375	45
60	28	81,000	325	390	15
61	--	--	--	--	--
62	35	81,000	360	400	20
63	35	81,000	375	415	40
5th Application					
59	30	81,000	350	Bolt broke	
60	15	81,000	350	400	15
61	--	--	--	--	--
62	25	81,000	365	425	Galled
63	30	81,000	360	Bolt broke	

TABLE VII (continued)

Part No. EWB 1615-4-38
Nut - FN 1418-428

6. Torque vs. Induced Load @ Room Temperature -

Torque, inch-pounds	Test No. 64 Load, pounds	Test No. 65 Load, pounds	Test No. 66 Load, pounds
50	1000	850	850
100	1900	2000	2000
150	2750	3000	3100
200	3850	3900	4200
250	5200	4900	5000
300	Bolt Broke	Bolt Broke	Bolt Broke

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
67	18	9	60	30,000	30	No Cracks	Passed
68	17	11	60	30,000	30	No Cracks	Passed
69	22	11	60	30,000	30	No Cracks	Passed
70	22	12	60	30,000	60	No Cracks	Passed
71	16	10	60	30,000	15	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area (.003 Red. Pitch Dia.) .03537 square inches.

(2) Stress calculated at twice nominal diameter area of .09817 square inches.

TABLE VIII

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-8-48 - Material - Waspaloy (150 ksi)
Part No. Nut FN 1418-820
Size: 1/2-20x3.741

1. Tensile - Base Material Properties (As Received)
.357 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	216,100	158,300	10.7	14.0
2	-423	220,400	149,100	12.8	16.2
3	-423	219,500	148,400	19.3	20.8
4	70	185,000	123,800	17.8	20.8
5	70	187,500	126,300	18.5	20.8
6	70	184,400	123,100	18.5	20.7
7	1400	133,600	109,000	14.2	23.7
8	1400	112,500	98,000	12.8	21.6
9	1400	113,500	97,500	11.4	18.3

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	31,800	201,000	24,500	155,000
11	-423	32,600	206,200	24,500	155,000
12	-423	31,500	199,000	24,750	157,000
13	70	26,400	167,300	20,000	126,700
14	70	26,500	167,900	19,875	126,000
15	70	26,700	169,200	20,300	128,600
16	1400	23,700	150,100	18,000	114,000
17	1400	24,200	153,900	18,500	117,200
18	1400	24,700	156,500	18,500	117,200

(1) Stress calculated at tensile stress area (.003 red pitch dia.), .1578 square inches.

TABLE VIII (continued)

Part No. EWB 1615-8-48
FN 1418-820

1. Tensile (continued) -

Base Material Properties (As cycled)
.357 Specimens
Cycled 12 Times
Seated at 83,000 psi

70° to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 1400°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, 1.4 in. %	Red. of Area, %
19	70	193,100	127,400	20.0	20.8
20	70	187,000	119,300	17.8	19.2
21	70	189,000	122,900	21.4	19.4

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 1400°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	26,200	166,000	18,900	119,800
23	70	26,300	166,700	19,600	124,200
24	70	27,000	171,000	20,300	128,600
		As Relaxed - 50 Hours			
Preload A					
25	70	27,500	176,800	20,000	126,700
26	70	27,400	173,600	19,800	125,500
27	70	28,000	177,400	22,400	142,000
Preload B					
28	70	27,500	174,300	20,600	130,500
29	70	27,300	173,000	20,600	130,500
30	70	27,500	174,300	19,400	122,900

Part No. EWB 1615-8-48
FN 1418-820

2. Double Shear -

(As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
31 (a)	-423	34,000	154,000
		Shear Fixture Failed	
32	70	47,500	121,000
33	70	49,500	126,100
34	70	49,800	126,800
35	1400	34,800	88,500
36	1400	35,800	91,000
37	1400	35,200	89,600

(a) .375 inch diameter

(As Cycled)

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 1400°F to 70°F

38	70	43,000	109,400
39	70	44,500	113,300
40	70	44,800	114,100

(As Relaxed - 50 hours)

Preload A

41	70	42,800	109,000
42	70	44,200	112,600
43	70	43,700	111,300

Preload B

44	70	44,800	114,100
45	70	45,200	115,100
46	70	39,200	100,000

(2) Stress calculated at twice nominal dia. area, .3927 square inches.

TABLE VIII (continued)

Part No. EWB 1615-8-48
FN 1418-820

3. Stress Rupture

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
47	1400	11,046	70,000	115.2	N. F.
48	1400	11,046	70,000	82.3	T
49	1400	11,046	70,000	146.0	N. F.
50	1400	15,780	100,000	6.3	T
51	1400	15,780	100,000	2.3	T
52	1400	15,780	100,000	4.8	T
53	1400	19,000	120,000	.8	T
54	1400	19,000	120,000	1.2	T
55	1400	19,000	120,000	.9	T

4. Stress Relaxation @ 1400°F

Preload A - Initial Stress - 74,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
56	10	6,690	42,400
57	10	5,791	36,700
58	10	6,580	41,700
59	50	3,180	20,150
60	50	2,943	18,650
61	50	2,700	17,100

Preload B - Initial Stress - 46,200 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
62	10	4,387	27,800
63	10	4,497	28,500
64	10	4,592	29,100
65	50	1,149	7,280
66	50	1,149	7,280
67	50	1,215	7,700

TABLE VIII (continued)

Part No. EWB 1615-8-48
Nut - FN 1418-820

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak	
				Breakaway	Removal
1st Application					
68	95	81,000	1000	850	50
69	80	81,000	1150	900	52
70	100	81,000	1000	800	70
71	140	81,000	1100	900	45
72	140	81,000	1050	850	65
2nd Application					
68	48	81,000	900	700	40
69	50	81,000	900	750	40
70	65	81,000	900	700	60
71	40	81,000	900	700	40
72	65	81,000	900	700	55
3rd Application					
68	43	81,000	850	700	40
69	45	81,000	900	700	45
70	60	81,000	850	700	55
71	40	81,000	900	700	40
72	60	81,000	800	650	55
4th Application					
68	45	81,000	850	650	42
69	45	81,000	900	700	35
70	60	81,000	850	700	55
71	45	81,000	900	700	40
72	55	81,000	800	600	55
5th Application					
68	45	81,000	800	600	35
69	45	81,000	850	700	42
70	55	81,000	850	700	50
71	50	81,000	850	700	50
72	60	81,000	800	700	55

TABLE VIII (continued)

Part No. EWB 1615-8-48
Nut - FN 1418-820

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 1400° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
73	110	81,000	1050	3800	100
74	105	81,000	1000	3600	100
75	100	81,000	1250	3400	80
76	120	81,000	1000	3400	130
77	110	81,000	1150	3000	90
2nd Application					
73	80	81,000	2760	3600	90
74	90	81,000	2640	3400	80
75	75	81,000	2820	3400	70
76	80	81,000	2880	3600	90
77	70	81,000	2640	3400	100
3rd Application					
73	70	81,000	3200	3600	60
74	80	81,000	3000	3600	60
75	80	81,000	2800	3600	60
76	100	81,000	2800	3600	100
77	80	81,000	2600	3600	70
4th Application					
73	50	81,000	2880	3600	80
74	80	81,000	2400	3200	60
75	80	81,000	2520	3400	60
76	90	81,000	2640	3600	70
77	100	81,000	2640	3400	70
5th Application					
73	60	81,000	3000	3400	60
74	70	81,000	3000	3600	60
75	75	81,000	3000	3600	60
76	80	81,000	2700	3200	80
77	80	81,000	2800	3400	80

TABLE VIII (continued)

Part No. EWB 1615-8-48
Nut - FN 1418-820

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 78 Load, pounds	Test No. 79 Load, pounds	Test No. 80 Load, pounds
250	1,500	1,500	1,500
500	4,000	4,250	3,500
750	6,500	7,500	6,250
1000	9,500	10,500	9,000
1250	12,500	14,500	11,500
1500	17,000	18,500	16,500
1750	19,500	20,000	18,000

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
81	55	35	300	30,000	30	No Cracks	Passed
82	55	40	300	30,000	30	No Cracks	Passed
83	60	35	300	30,000	30	No Cracks	Passed
84	55	38	300	30,000	40	No Cracks	Passed
85	50	40	300	30,000	35	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area (.003 Red. Pitch Dia.) .1578 square inches.

(2) Stress calculated at twice nominal diameter area, .3927 square inches.

TABLE IX

SUMMARY OF RESULTS

EWBT815 & FN1216 - MATERIAL Ti7Al-12Zr (150 KSI)

Material Properties

Test Temp.	U.T.S. - KSI #10	U.T.S. - KSI 1/4	U.T.S. - KSI 1/2	0.2% Offset Yield - KSI #10	0.2% Offset Yield - KSI 1/4	0.2% Offset Yield - KSI 1/2	Elongation - % #10	Elongation - % 1/4	Elongation - % 1/2
-423°F	272.5	280.0	232.6	247.3	269.0	212.3	6.0	6.0	3.6
	267.0	291.8	235.0	255.8	267.4	213.0	6.0	6.0	3.6
	283.2	265.0	234.0	271.1	242.5	202.5	6.0	4.0	4.3
70°F	160.7	160.4	153.5	153.0	140.6	143.0	14.0	10.0	15.0
	156.3	159.3	153.7	151.5	147.3	145.7	14.0	10.0	14.2
	158.6	161.4	151.1	155.9	144.7	141.3	14.0	10.0	13.5
750°F	117.0	119.8	113.0	92.5	93.9	97.5	18.0	19.0	25.0
	114.0	115.8	112.0	93.4	89.3	97.0	18.0	20.0	21.4
	116.6	117.8	114.5	92.7	87.8	99.2	18.0	20.0	21.4

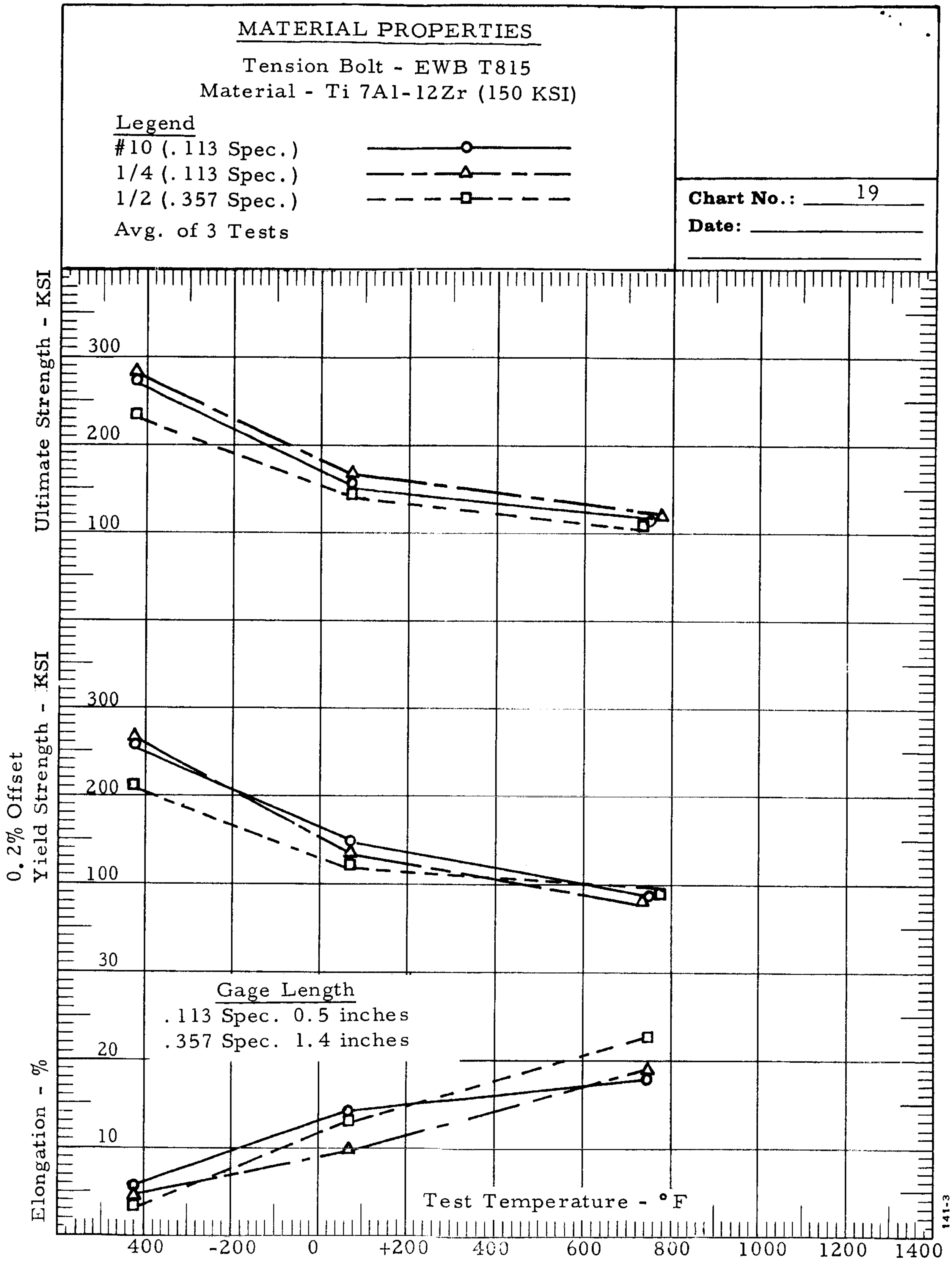
Test Temp.	Reduction of Area - % #10	Reduction of Area - % 1/4	Reduction of Area - % 1/2	Shear Strength - KSI #10	Shear Strength - KSI 1/4	Shear Strength - KSI 1/2
-423°F	—	17.2	9.6	148.1	135.5	127.2
	14.4	14.0	—	143.5	146.7	128.0
	17.4	10.0	9.9	149.9	137.5	131.0
70°F	39.8	38.5	44.5	109.0	105.9	105.7
	36.2	38.5	43.3	106.3	107.0	107.0
	37.9	38.5	41.3	108.0	107.0	105.9
750°F	48.7	47.8	52.9	69.2	64.2	72.7
	49.0	48.9	54.0	68.8	68.2	73.0
	49.3	50.2	51.4	68.3	73.3	75.0

Bolt & Nut Properties -

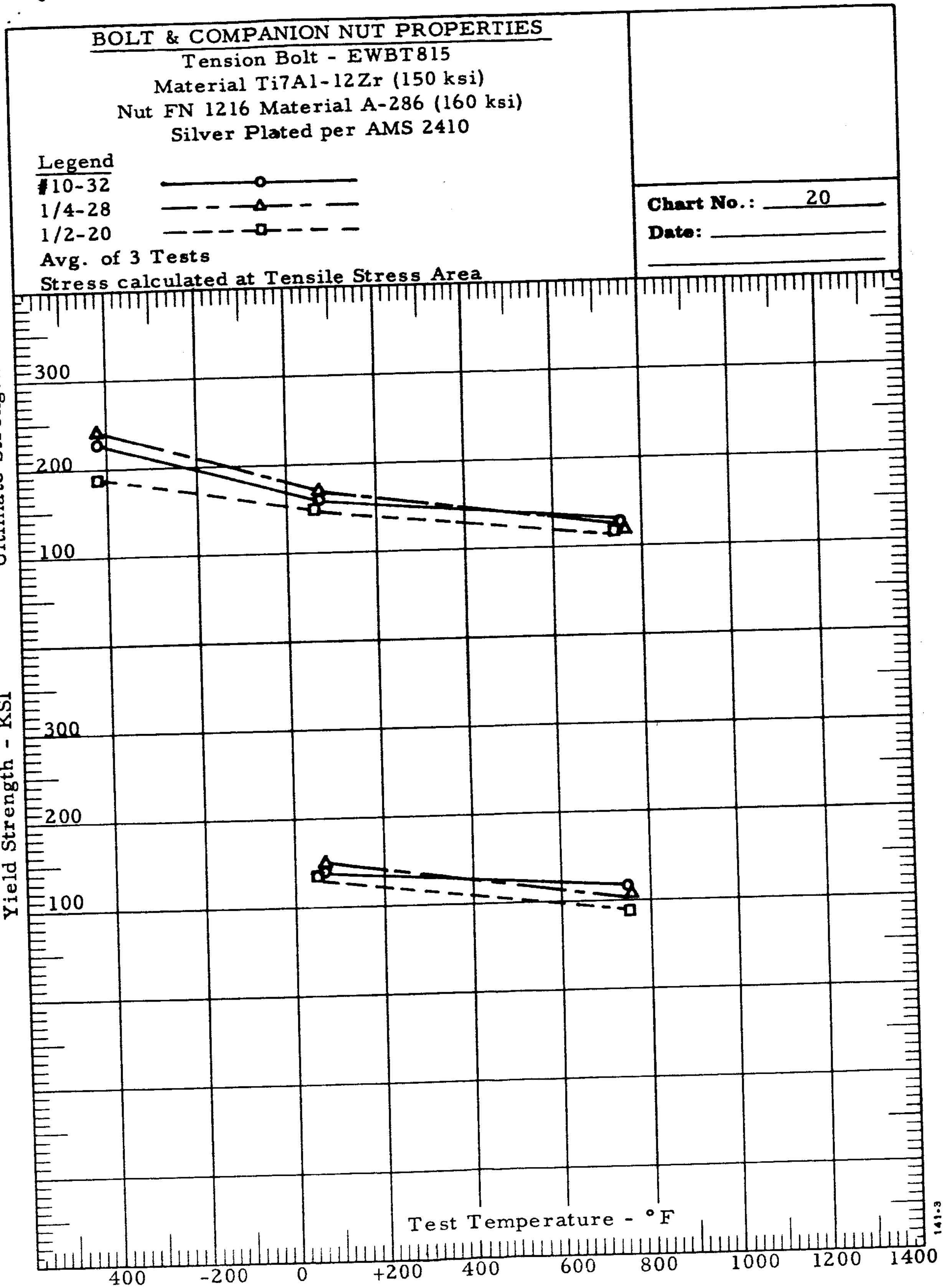
Test Temp.	U. T. S. - KSI (1) #10	U. T. S. - KSI (1) 1/4	U. T. S. - KSI (1) 1/2	Johnson's 2/3 Approx. Yield - KSI #10	Johnson's 2/3 Approx. Yield - KSI 1/4	Johnson's 2/3 Approx. Yield - KSI 1/2
-423°F	224.1	240.6	216.0	N.Y.	N.Y.	N.Y.
	228.1	225.5	180.0	N.Y.	N.Y.	N.Y.
	230.1	255.7	191.0	N.Y.	N.Y.	N.Y.
70°F	162.5	167.7	156.3	141.3	151.2	143.8
	165.0	166.3	157.5	145.0	142.9	142.5
	165.0	166.3	157.5	143.8	149.8	140.7
750°F	128.5	123.7	123.2	110.0	98.9	106.3
	130.1	125.7	120.3	116.3	107.9	95.0
	130.5	125.1	116.3	117.5	108.6	96.3

N.Y. - No Yield

(1) Stress calculated at tensile stress area



MATERIAL PROPERTIES
Tension Bolt - EWB T815
Material - Ti 7Al-12Zr (150 KSI)
Legend
#10 (.113 Spec.)
1/4 (.113 Spec.)
1/2 (.357 Spec.)
Avg. of 3 Tests
Chart No.: 19
Date:
Ultimate Strength - KSI
300
200
100
0.2% Offset Yield Strength - KSI
300
200
100
30
Gage Length
.113 Spec. 0.5 inches
.357 Spec. 1.4 inches
Elongation - %
20
10
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3


BOLT & COMPANION NUT PROPERTIES
Tension Bolt - EWBT815
Material Ti7Al-12Zr (150 ksi)
Nut FN 1216 Material A-286 (160 ksi)
Silver Plated per AMS 2410
Legend
#10-32
1/4-28
1/2-20
Avg. of 3 Tests
Stress calculated at Tensile Stress Area
Chart No.: 20
Date:
Ultimate Strength - KSI
300
200
100
Johnson's 2/3 Approx.
Yield Strength - KSI
300
200
100
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400

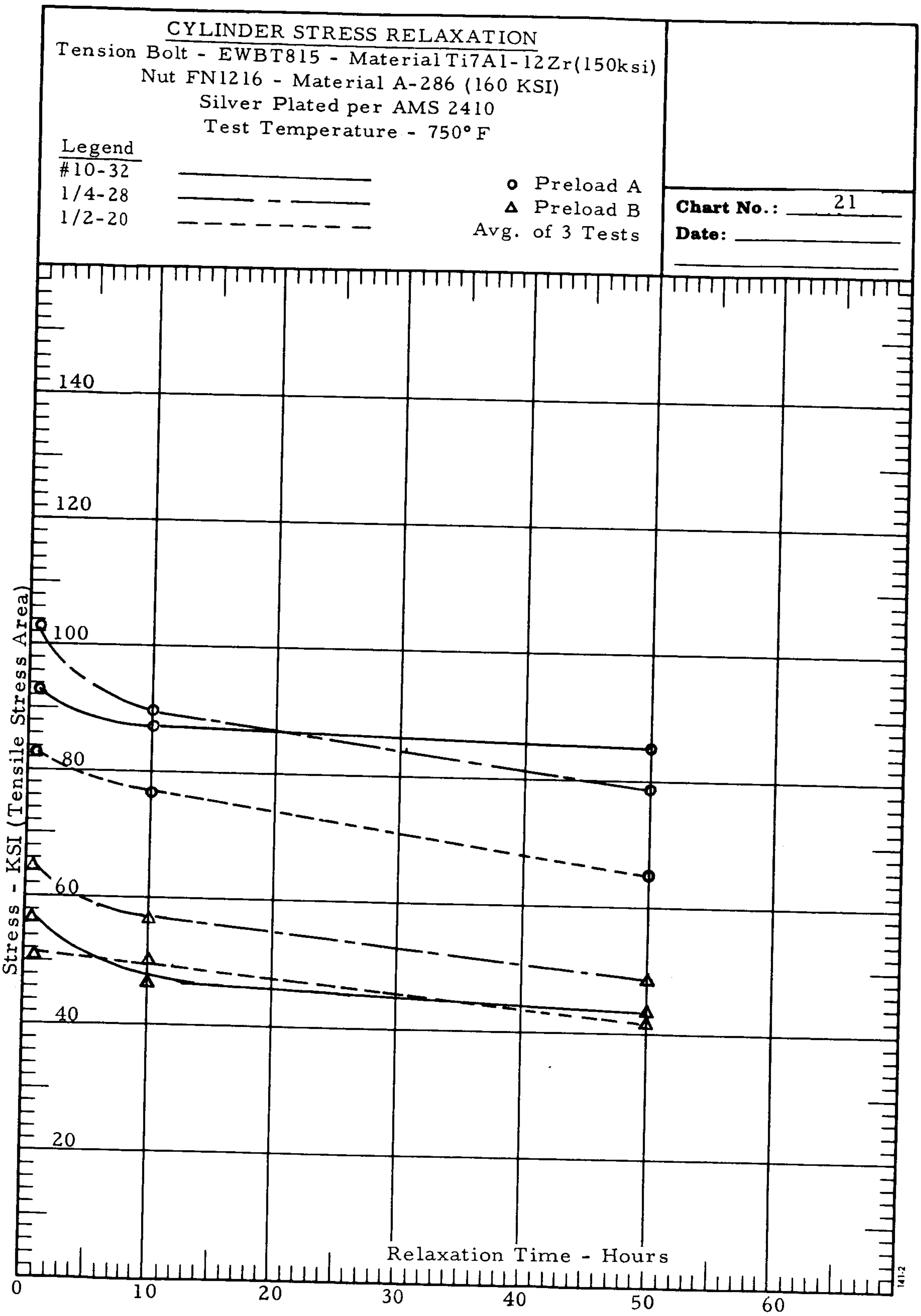

CYLINDER STRESS RELAXATION
Tension Bolt - EWBT815 - Material Ti7Al-12Zr(150ksi)
Nut FN1216 - Material A-286 (160 KSI)
Silver Plated per AMS 2410
Test Temperature - 750° F
Legend
#10-32
1/4-28
1/2-20
Preload A
Preload B
Avg. of 3 Tests
Chart No.: 21
Date:
Stress - KSI (Tensile Stress Area)
140
120
100
80
60
40
20
Relaxation Time - Hours
0
10
20
30
40
50
60

TABLE X

MECHANICAL PROPERTIES

Part No. EWBT 815-3-34 - Material - Ti 7Al-12Zr (150 ksi)
Part No. Nut FN 1216-1032 - Material A-286 (160 ksi)
Size - #10-32

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	272,500	247,300	6.0	-
2	-423	267,000	255,800	6.0	14.4
3	-423	283,200	271,100	6.0	17.4
4	70	160,700	153,000	14.0	39.8
5	70	156,300	151,500	14.0	36.2
6	70	158,600	155,900	14.0	37.9
7	750	117,000	92,500	18.0	48.7
8	750	114,700	93,400	18.0	49.0
9	750	116,600	92,700	18.0	49.3

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	4,480	224,100	No Yield	
11	-423	4,560	228,100	No Yield	
12	-423	4,600	230,100	No Yield	
13	70	3,250	162,500	2,825	141,300
14	70	3,300	165,000	2,900	145,000
15	70	3,300	165,000	2,875	143,800
16	750	2,570	128,500	2,200	110,000
17	750	2,600	130,100	2,325	116,300
18	750	2,610	130,500	2,350	117,500

(1) Stress calculated at tensile stress area of .01999 square inches.

TABLE X (continued)

Part No. EWBT 815-3-34
FN 1216-1032

1. Tensile (continued) -

Base Material Properties (As cycled)
.113 Specimens
Cycled 12 Times
Seated at 77,000 psi

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
19	70	156,700	139,100	16.0	40.0
20	70	156,800	137,900	16.0	39.0
21	70	157,700	139,200	16.0	41.3

70°F to 750°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
22	70	158,300	144,700	14.0	40.0
23	70	156,200	140,000	14.0	40.0
24	70	156,800	141,000	16.0	40.4

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
25	70	3,360	168,100	2,930	146,600
26	70	3,380	169,100	2,960	148,000
27	70	3,370	168,600	2,940	147,100

70°F to 750°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
28	70	3,180	159,000	2,900	145,000
29	70	3,170	158,500	2,900	145,000
30	70	3,120	156,000	2,900	145,000

TABLE X (continued)

Part No. EWBT 815-3-34
FN 1216-10-32

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
31	70	3,380	169,100	3.040	152,100
32	70	3,250	162,600	2,940	147,100
33	70	3,420	172,100	3,175	158,800
Preload B					
34	70	3,150	157,500	2,820	141,000
35	70	3,200	160,000	2,910	145,000
36	70	Bolt was damaged in disassembly.			

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
37	-423	8,400	148,100
38	-423	8,140	143,500
39	-423	8,500	149,900
40	70	5,300	93,500
41	70	5,380	94,800
42	70	5,360	94,500
43	750	3,925	69,200
44	750	3,900	68,800
45	750	3,875	68,300

TABLE X (continued)

Part No. EWBT 815-3-34
FN 1216-1032

2. Double Shear (continued) -

"As Cycled"

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
46	70	5,530	97,500
47	70	5,560	98,000
48	70	5,540	97,700

70°F to 750°F to 70°F

49	70	5,450	96,100
50	70	5,410	95,400
51	70	5,390	95,100

As Relaxed (50 hours)

Preload A

52	70	6,000	105,800
53	70	5,890	103,900
54	70	5,990	105,600

Preload B

55	70	5,960	105,200
56	70	6,100	108,000
57	70	Bolt was damaged in disassembly.	

(2) Stress calculated at twice nominal dia., .05671 square inches

TABLE X (continued)

Part No. EWBT 815-3-34
FN 1216-1032

3. Stress Rupture -

Stress rupture tests at 750°F were not conducted. Fastener assembly is not rupture sensitive as evidenced by 1/4 inch results. The stress required for 100 hour life was above the 750°F yield strength.

4. Stress Relaxation @ 750°F -

Preload A - Initial Stress - 92,750 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
58	10	1,760	88,000
59	10	1,772	86,125
60	50	1,680	84,000
61	50	1,700	85,000
62	50	1,720	86,000

Preload B - Initial Stress - 57,500 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
63	10	850	42,500
64	10	955	47,750
65	10	1,000	50,000
66	50	870	43,500
67	50	800	40,000
68	50	Bolt was damaged in disassembly	

TABLE X (continued)

Part No. EWBT 815-3-34
Nut - FN 1216-1032

5. Nut Reuse and Galling Tendency -

After Soak @ -423° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
69	8	81,000	68	50	7
70	12	81,000	65	45	11
71	9	81,000	68	45	8
72	12	81,000	67	42	12
73	--	--	--	--	--
2nd Application					
69	10	81,000	60	45	11
70	12	81,000	60	48	13
71	9	81,000	63	45	9
72	14	81,000	65	48	14
73	--	--	--	--	--
3rd Application					
69	10	81,000	60	45	8
70	14	81,000	65	50	11
71	9	81,000	65	50	9
72	12	81,000	65	45	10
73	--	--	--	--	--
4th Application					
69	7	81,000	63	45	7
70	10	81,000	63	50	12
71	6	81,000	65	50	7
72	11	81,000	63	50	11
73	--	--	--	--	--
5th Application					
69	11	81,000	60	45	8
70	16	81,000	65	50	13
71	11	81,000	60	50	8
72	15	81,000	65	50	11
73	--	--	--	--	--

TABLE X (continued)

Part No. EWBT 815-3-34
Nut - FN 1216-1032

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
74	9	81,000	60	45	10
75	13	81,000	60	45	10
76	13	81,000	63	45	12
77	8	81,000	60	43	10
78	9	81,000	58	43	9
2nd Application					
74	10	81,000	60	43	10'
75	12	81,000	59	43	13
76	13	81,000	62	45	12
77	10	81,000	60	43	10
78	9	81,000	55	43	10
3rd Application					
74	10	81,000	60	40	11
75	15	81,000	58	42	15
76	14	81,000	60	45	13
77	11	81,000	61	45	12
78	9	81,000	59	41	10
4th Application					
74	11	81,000	60	43	11
75	15	81,000	60	43	12
76	13	81,000	65	43	13
77	12	81,000	63	45	12
78	10	81,000	58	43	12
5th Application					
74	11	81,000	60	43	11
75	11	81,000	60	41	13
76	11	81,000	60	47	13
77	12	81,000	60	44	10
78	12	81,000	58	45	13

TABLE X (continued)

Part No. EWBT 815-3-34
Nut - FN 1216-1032

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 750° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
79	8	81,000	58	75	8
80	11	81,000	60	80	14
81	10	81,000	60	75	11
82	11	81,000	60	75	11
83	11	81,000	60	75	12
2nd Application					
79	8	81,000	60	80	10
80	12	81,000	65	80	13
81	8	81,000	58	75	11
82	10	81,000	60	80	10
83	10	81,000	58	75	10
3rd Application					
79	7	81,000	58	70	8
80	12	81,000	60	70	14
81	8	81,000	60	75	11
82	8	81,000	60	70	10
83	8	81,000	60	75	11
4th Application					
79	10	81,000	60	65	9
80	15	81,000	60	60	14
81	8	81,000	58	70	12
82	8	81,000	60	80	12
83	11	81,000	60	60	12
5th Application					
79	10	81,000	60	65	12
80	16	81,000	60	70	14
81	9	81,000	58	75	12
82	10	81,000	58	80	15
83	12	81,000	60	65	13

TABLE X (continued)

Part No. EWBT 815-3-34
Nut - FN 1216-1032

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 84 Load, pounds	Test No. 85 Load, pounds	Test No. 86 Load, pounds
50	800	1000	950
75	1800	2000	2000
100	2600	2750	3000
125	3100	3100	3250

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
87	12	8	30	30,000	0	No Cracks	Passed
88	10	8	30	30,000	0	No Cracks	Passed
89	13	9	30	30,000	0	No Cracks	Passed
90	15	12	30	30,000	0	No Cracks	Passed
91	12	7	30	30,000	0	No Cracks	Passed

(1) Stress calculated at Tensile Stress are of .01999 square inches.

(2) Stress calculated at twice nominal diameter area, .05671 square inches.

TABLE XI

MECHANICAL PROPERTIES

Part No. EWBT 815-4-38 - Material - Ti 7Al-12Zr (150 ksi)
Part No. Nut FN1216-428 - Material A-286 (160 ksi)
Size - 1/4-28

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	280,000	269,000	6.0	17.2
2	-423	291,800	267,500	6.0	14.0
3	-423	265,000	242,500	4.0	10.0
4	70	160,400	140,600	10.0	38.5
5	70	159,300	147,300	10.0	38.5
6	70	161,400	144,700	10.0	38.5
7	750	119,800	93,900	18.0	47.8
8	750	115,800	89,300	20.0	48.9
9	750	117,800	87,800	20.0	50.2

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	8,750	240,600	No Yield	
11	-423	8,200	225,500	No Yield	
12	-423	9,300	255,700	No Yield	
13	70	6,100	167,700	5,500	151,200
14	70	6,050	166,300	5,200	142,900
15	70	6,050	166,300	5,450	149,800
16	750	4,500	123,700	3,600	98,900
17	750	4,547	125,700	3,925	107,900
18	750	4,550	125,100	3,950	108,600

(1) Stress calculated at tensile stress area of .03637 square inches.

TABLE XI (continued)

Part No. EWBT 815-4-38
FN 1216-428

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	70	5,980	164,400	5,530	152,000
20	70	5,850	160,800	5,420	149,000
21	70	5,800	159,400	5,410	148,700
Preload B					
22	70	5,840	160,600	5,500	151,200
23	70	5,820	160,000	5,550	152,600
24	70	5,690	156,400	5,350	147,100

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
25	-423	13,300	135,500
26	-423	14,400	146,700
27	-423	13,500	137,500
28	70	10,400	105,900
29	70	10,500	107,000
30	70	10,500	107,000
31	750	6,300	64,200
32	750	6,700	68,200
33	750	7,200	73,300

(2) Stress calculated at twice nominal dia. area, .09817 square inches.

TABLE XI (continued)

Part No. EWBT 815-4-38
FN 1216-428

2. Double Shear -

"As Relaxed" (50 hrs.)

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
34	70	10,500	107,000
35	70	10,400	105,900
36	70	10,500	107,000
Preload B			
37	70	10,200	103,900
38	70	10,000	101,900
39	70	10,100	102,900

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
40	750	4,073	112,000	113	N. F.
41	750	4,073	112,000	139	N. F.
42	750	4,073	112,000	132	N. F.
43	750	4,364	120,000	100	N. F.
44	750	4,546	125,000	62.6	T
45	750	4,546	125,000	100	N. F.
46	750	4,546	125,000	100	N. F.
47	750	4,546	125,000	Failed Loading	
48	750	4,546	125,000	100	N. F.

TABLE XI (continued)

Part No. EWBT 815-4-38
FN 1216-428

4. Stress Relaxation @ 750°F

Preload A - Initial Stress - 103,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi[1]
49	10	3,400	93,500
50	10	3,146	86,500
51	10	3,218	88,500
52	50	2,946	81,000
53	50	2,851	78,400
54	50	2,800	77,000

Preload B - Initial Stress - 64,200 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi[1]
55	10	2,080	57,200
56	10	2,080	57,200
57	10	2,051	56,400
58	50	1,749	48,100
59	50	1,700	46,750
60	50	1,800	49,500

TABLE XI (continued)

Part No. EWBT 815-4-38
FN 1216-428

5. Nut Reuse and Galling Tendency -

After Soak @ -423° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
61	25	81,000	130	100	24
62	24	81,000	130	100	16
63	25	81,000	125	110	20
64	27	81,000	130	110	18
65	27	81,000	135	110	27
2nd Application					
61	25	81,000	120	100	28
62	28	81,000	125	100	25
63	27	81,000	125	105	27
64	30	81,000	130	110	20
65	30	81,000	135	100	23
3rd Application					
61	18	81,000	125	100	22
62	20	81,000	130	100	20
63	40	81,000	120	100	22
64	24	81,000	135	110	22
65	30	81,000	135	105	20
4th Application					
61	30	81,000	125	100	25
62	22	81,000	125	90	22
63	26	81,000	123	100	22
64	28	81,000	130	100	28
65	33	81,000	135	100	30
5th Application					
61	30	81,000	125	100	22
62	28	81,000	130	100	19
63	35	81,000	125	110	25
64	27	81,000	125	100	20
65	22	81,000	130	105	22

TABLE XI (continued)

Part No. EWBT 815-4-38
Nut - FN 1216-428

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
66	24	81,000	125	95	20
67	22	81,000	125	100	20
68	28	81,000	130	100	17
69	22	81,000	110	80	15
70	23	81,000	125	90	17
2nd Application					
66	24	81,000	130	85	19
67	24	81,000	125	90	24
68	26	81,000	120	95	24
69	24	81,000	120	90	20
70	25	81,000	125	90	22
3rd Application					
66	24	81,000	130	90	20
67	24	81,000	130	90	22
68	28	81,000	120	95	25
69	28	81,000	125	90	24
70	26	81,000	125	100	24
4th Application					
66	22	81,000	120	90	22
67	23	81,000	125	100	24
68	25	81,000	125	95	25
69	27	81,000	125	95	22
70	28	81,000	130	95	22
5th Application					
66	25	81,000	120	100	21
67	24	81,000	125	95	20
68	26	81,000	125	95	23
69	25	81,000	120	80	20
70	25	81,000	120	85	18

TABLE XI (continued)

Part No. EWBT 815-4-38
Nut - FN 1216-428

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 750° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
71	25	81,000	120	160	16
72	16	81,000	120	160	14
73	22	81,000	110	160	12
74	18	81,000	125	160	14
75	24	81,000	130	170	14
2nd Application					
71	22	81,000	105	160	23
72	16	81,000	100	140	15
73	16	81,000	90	140	15
74	18	81,000	95	125	16
75	20	81,000	115	140	20
3rd Application					
71	24	81,000	140	180	24
72	20	81,000	145	150	16
73	18	81,000	120	160	14
74	17	81,000	150	170	16
75	24	81,000	145	170	20
4th Application					
71	24	81,000	170	180	25
72	20	81,000	140	160	18
73	16	81,000	140	170	15
74	18	81,000	150	180	16
75	23	81,000	155	170	21
5th Application					
71	24	81,000	150	170	24
72	22	81,000	150	150	20
73	16	81,000	145	160	14
74	16	81,000	160	170	16
75	22	81,000	150	160	21

TABLE XI (continued)

Part No. EWBT 815-4-38
Nut - FN 1216-428

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 76 Load, pounds	Test No. 77 Load, pounds	Test No. 78 Load, pounds
50	500	450	
100	1950	1750	1500
150	3300	3000	2650
200	5000	5000	4000
225	5500 (B.B.)	5500 (B.B.)	-
250			5250
			5500 (B.B.)

B.B. - Bolt Broke

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
79	35	20	60	30,000	0	No Cracks	Passed
80	30	15	60	30,000	0	No Cracks	Passed
81	25	15	60	30,000	0	No Cracks	Passed
82	28	20	60	30,000	0	No Cracks	Passed
83	25	13	60	30,000	0	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area of .03637 square inches.

(2) Stress calculated at twice nominal diameter area, .09817 square inches.

TABLE XII

MECHANICAL PROPERTIES

Part No. EWBT 815-8-46 - Material - Ti 7Al-12Zr (150 ksi)
Part No. Nut FN 1216-820 Material A-286 (160 ksi)
Size - 1/2-20

1. Tensile - Base Material Properties (As Received)
.357 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	232,600	212,300	3.6	9.6
2	-423	235,000	213,000	3.6	-
3	-423	234,000	202,500	4.3	9.9
4	70	153,500	143,000	15.0	44.5
5	70	153,700	145,700	14.2	43.3
6	70	151,100	141,300	13.5	41.3
7	750	113,000	97,500	25.0	52.9
8	750	112,000	97,000	21.4	54.0
9	750	114,500	99,200	21.4	51.4

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	34,500	216,000	No Yield	
11	-423	28,800	180,000	No Yield	
12	-423	30,500	191,000	No Yield	
13	70	25,000	156,300	23,000	143,800
14	70	25,200	157,500	22,800	142,500
15	70	25,200	157,500	22,500	140,700
16	750	19,700	123,200	17,000	106,300
17	750	19,250	120,300	15,200	95,000
18	750	18,600	116,300	15,400	96,300

(1) Stress calculated at tensile stress area of .1599 square inches.

TABLE XII (continued)

Part No. EWBT 815-8-46
FN 1216-820

1. Tensile (continued) -

Base Material Properties (As cycled)
.357 Specimens
Cycled 12 Times
Seated at 77,000 psi

70° to -423°F to 70°F - Cycling Tests Not Conducted

70°F to 750°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
19	70	149,300	140,600	18.0	47.0
20	70	151,600	143,500	19.1	35.0
21	70	150,700	143,200	17.1	35.4

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F - Cycling Tests Not Conducted

70°F to 750°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	24,000	150,100	22,250	139,100
23	70	24,800	155,100	22,250	139,100
24	70	23,600	147,600	22,250	139,100
		As Relaxed - 50 Hours			
Preload A					
25	70	21,500	134,400	21,000	131,300
26	70	21,700	135,700	21,500	134,500
27	70	23,300	145,700	22,000	137,600
Preload B					
28	70	22,000	137,500	21,750	136,000
29	70	23,500	146,900	23,250	145,400
30	70	23,500	146,900	No Yield	

TABLE XII (continued)

Part No. EWBT 815-8-46
FN 1216-820

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
31	-423	50,000	127,200
32	-423	50,300	128,000
33	-423	51,500	131,000
34	70	41,500	105,700
35	70	42,000	107,000
36	70	41,600	105,900
37	750	28,500	72,700
38	750	28,600	73,000
39	750	29,500	75,000

"As Cycled"

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 750°F to 70°F

40	70	41,300	102,600
41	70	41,600	105,900
42	70	40,300	102,600

"As Relaxed" (50 hours)

Preload A

43	70	40,300	102,600
44	70	40,300	102,600
45	70	39,200	99,800

Preload B

46	70	39,300	101,000
47	70	39,200	99,800
48	70	39,000	99,300

(2) Stress calculated at twice nominal dia., .3927 square inches.

TABLE XII (continued)

Part No. EWBT 815-8-46
FN 1216-820

3. Stress Rupture -

Stress rupture tests at 750° F were not conducted. Fastener assembly is not considered rupture sensitive as evidenced by 1/4 inch results. The stress required for 100 hour life was above the 750° F yield strength.

4. Stress Relaxation @ - 750° F

Preload A - Initial Stress - 82,800 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi[1]
49	10	11,800	73,800
50	10	12,472	78,200
51	10	12,248	76,600
52	50	10,298	64,400
53	50	10,490	65,600
54	50	10,234	64,000

Preload B - Initial Stress - 51,600 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi[1]
55	10	8,155	51,000
56	10	8,155	51,000
57	10	7,739	48,400
58	50	6,396	40,000
59	50	6,680	41,800
60	50	6,748	42,200

TABLE XII (continued)

Part No. EWBT 815-8-46
Nut - FN 1216-820 - Coated with SPS K_2 MoS_2

5. Nut Reuse and Galling Tendency -

After Soak @ 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
61	60	81,000	800	600	55
62	60	81,000	750	600	70
63	30	81,000	825	650	40
64	65	81,000	775	625	70
65	35	81,000	750	600	30
2nd Application					
61	50	81,000	825	600	50
62	45	81,000	750	600	60
63	30	81,000	800	600	30
64	40	81,000	750	600	60
65	25	81,000	725	575	25
3rd Application					
61	55	81,000	800	575	60
62	45	81,000	775	600	55
63	25	81,000	850	625	30
64	40	81,000	750	600	60
65	25	81,000	725	575	30
4th Application					
61	60	81,000	825	575	70
62	45	81,000	725	575	55
63	25	81,000	800	625	35
64	50	81,000	750	600	60
65	25	81,000	725	600	30
5th Application					
61	70	81,000	800	575	80
62	45	81,000	750	575	60
63	25	81,000	800	600	30
64	40	81,000	775	625	60
65	25	81,000	725	575	30

TABLE XII (continued)

Part No. EWBT 815-8-46
Nut - FN 1216-820 - Coated with SPS K_2MoS_2

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 750° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
66	65	81,000	825	750	85
67	25	81,000	700	675	60
68	60	81,000	825	750	70
69	25	81,000	725	600	35
70	60	81,000	750	650	70
2nd Application					
66	30	81,000	825	750	80
67	25	81,000	725	675	50
68	25	81,000	800	800	75
69	20	81,000	725	700	50
70	35	81,000	750	700	65
3rd Application					
66	30	81,000	850	800	85
67	30	81,000	700	650	45
68	25	81,000	800	800	75
69	25	81,000	700	750	45
70	45	81,000	725	700	70
4th Application					
66	30	81,000	825	750	80
67	30	81,000	750	775	65
68	30	81,000	800	800	80
69	30	81,000	725	800	60
70	60	81,000	750	750	70
5th Application					
66	40	81,000	800	800	90
67	50	81,000	725	750	70
68	30	81,000	800	800	85
69	35	81,000	700	900	60
70	60	81,000	750	750	70

TABLE XII (continued)

Part No. EWBT 815-8-46
Nut - FN 1216-820

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 71 Load, pounds	Test No. 72 Load, pounds	Test No. 73 Load, pounds
360	2,500	2,500	2,700
600	5,750	5,250	6,000
840	9,500	7,500	9,000
1080	12,250	10,000	12,500
1320	13,750	13,500	14,500
1560	16,250	16,250	17,500
1800	19,250	19,500	19,500
2040	22,000	22,000	21,500
		Bolt Broke	

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
74	120	150	300	30,000	0	No Cracks	Passed
75	185	150	300	30,000	0	No Cracks	Passed
76	100	130	300	30,000	0	No Cracks	Passed
77	135	145	300	30,000	0	No Cracks	Passed
78	135	150	300	30,000	0	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area of .1599 square inches.

(2) Stress calculated at twice nominal diameter area .3927 square inches.

TABLE XIII

SUMMARY OF RESULTS

VS 1134, NAS 1271, NAS 1275 & FN1216 - MATERIAL Ti6A1-4V (160 KSI)

Material Properties -

Test Temp.	U.T.S. - KSI #10	U.T.S. - KSI 1/4	U.T.S. - KSI 1/2	0.2% Offset Yield - KSI #10	0.2% Offset Yield - KSI 1/4	0.2% Offset Yield - KSI 1/2	Elongation - % #10	Elongation - % 1/4	Elongation - % 1/2
-423°F	335.0	306.2	281.4	-	288.0	281.4	6.0	5.0	3.6
	341.0	311.0	277.4	313.0	296.0	274.4	4.0	4.0	4.3
	338.0	308.2	276.1	314.0	294.5	263.7	4.0	5.0	2.9
70°F	181.2	168.4	170.8	170.8	158.7	158.7	12.0	12.0	14.2
	182.2	168.5	171.7	169.7	162.9	160.5	12.0	10.0	14.2
	182.7	166.6	169.7	169.3	159.6	155.4	12.0	10.0	14.2
400°F	142.8	136.0	139.5	134.6	127.0	121.0	14.0	16.0	16.4
	151.0	136.8	141.5	128.5	128.4	123.3	14.0	14.0	17.8
	144.7	133.6	141.5	132.8	125.2	128.5	16.0	12.0	15.0

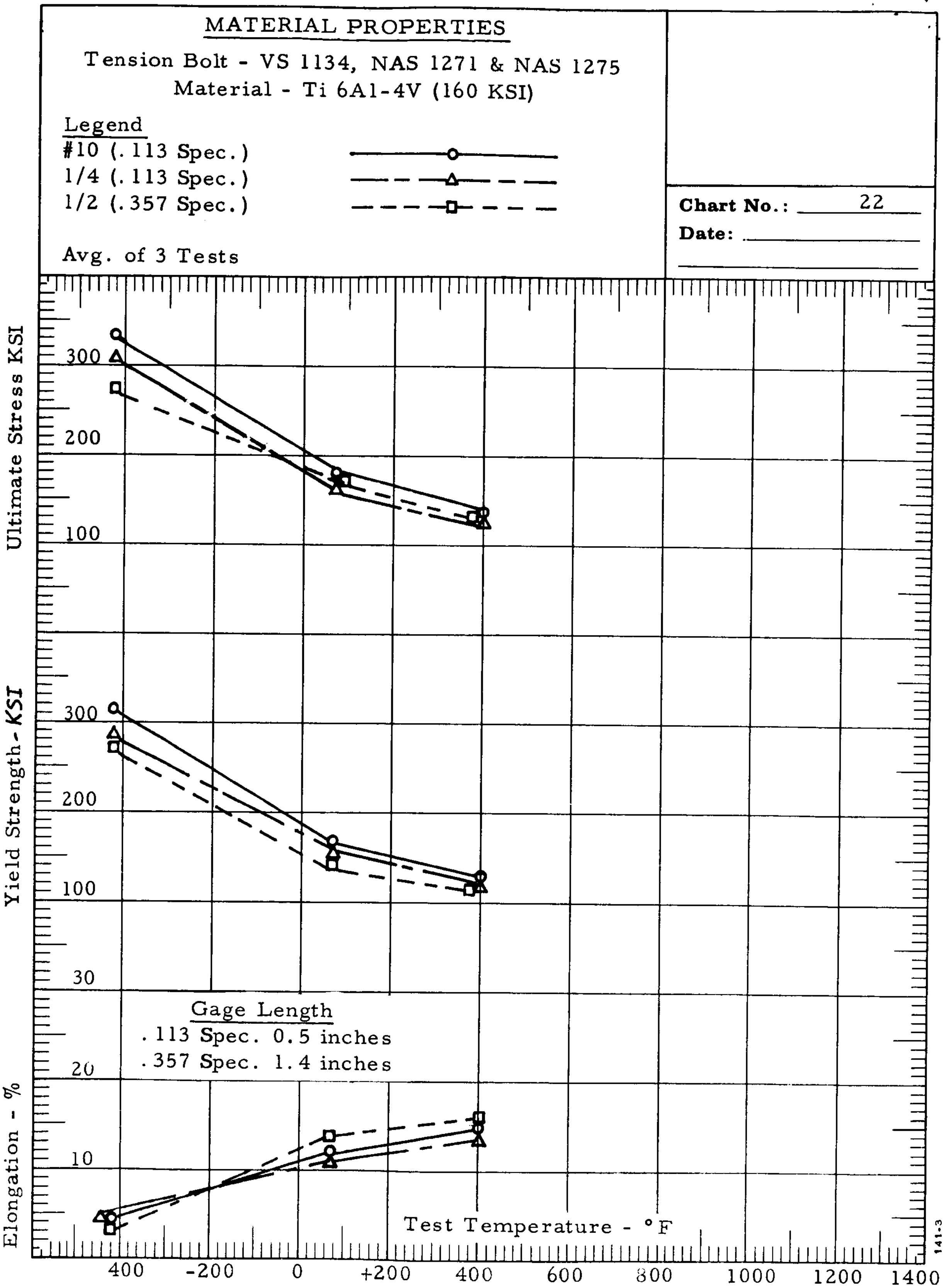
Test Temp.	Reduction of Area - % #10	Reduction of Area - % 1/4	Reduction of Area - % 1/2	Shear Strength - KSI #10	Shear Strength - KSI 1/4	Shear Strength - KSI 1/2
-423°F	23.0	13.6	17.5	156.9	142.6	Test
	5.5	9.0	24.3	171.0	143.6	Not
	12.0	12.3	17.9	163.1	131.4	Conducted
70°F	44.0	49.8	49.6	113.4	111.0	110.0
	44.0	51.8	52.9	115.7	109.5	111.0
	48.9	51.0	51.3	115.5	112.0	108.2
400°F	57.6	58.0	63.6	83.8	81.5	87.5
	45.0	58.3	64.4	85.5	80.5	89.7
	55.5	59.5	64.0	82.9	76.4	87.0

Bolt & Nut Properties -

Test Temp.	U.T.S. - KSI (1) #10	U.T.S. - KSI (1) 1/4	U.T.S. - KSI (1) 1/2	Johnson's 2/3 Approx. Yield - KSI #10	Johnson's 2/3 Approx. Yield - KSI 1/4	Johnson's 2/3 Approx. Yield - KSI 1/2
-423°F	251.1	245.3	203.0	N.Y.	N.Y.	N.Y.
	267.6	266.7	236.0	N.Y.	N.Y.	N.Y.
	241.6	239.8	202.0	N.Y.	N.Y.	N.Y.
70°F	178.5	185.5	184.4	165.0	168.4	168.2
	182.5	178.0	185.7	170.0	151.2	168.8
	182.5	178.7	185.1	170.0	153.9	166.9
400°F	167.5	140.2	156.3	152.5	113.4	142.2
	163.0	147.0	152.5	150.0	126.4	140.7
	162.0	147.0	152.5	148.5	130.6	138.8

N.Y. - No Yield

(1) Stress calculated at tensile stress area



MATERIAL PROPERTIES
Tension Bolt - VS 1134, NAS 1271 & NAS 1275
Material - Ti 6A1-4V (160 KSI)
Legend
#10 (.113 Spec.)
1/4 (.113 Spec.)
1/2 (.357 Spec.)
Avg. of 3 Tests
Chart No.: 22
Date:
Ultimate Stress KSI
300
200
100
0.2% Offset Yield Strength - KSI
300
200
100
30
20
10
Elongation - %
Gage Length
.113 Spec. 0.5 inches
.357 Spec. 1.4 inches
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400

BOLT & COMPANION NUT PROPERTIES

Bolt - VS1134, NAS 1271 & NAS 1275

Material Ti6Al-4V (160 KSI)

Nut - FN1216 - Material A-286 (160 KSI)

Legend

#10-32 ——o——

1/4-28 – – △ – –

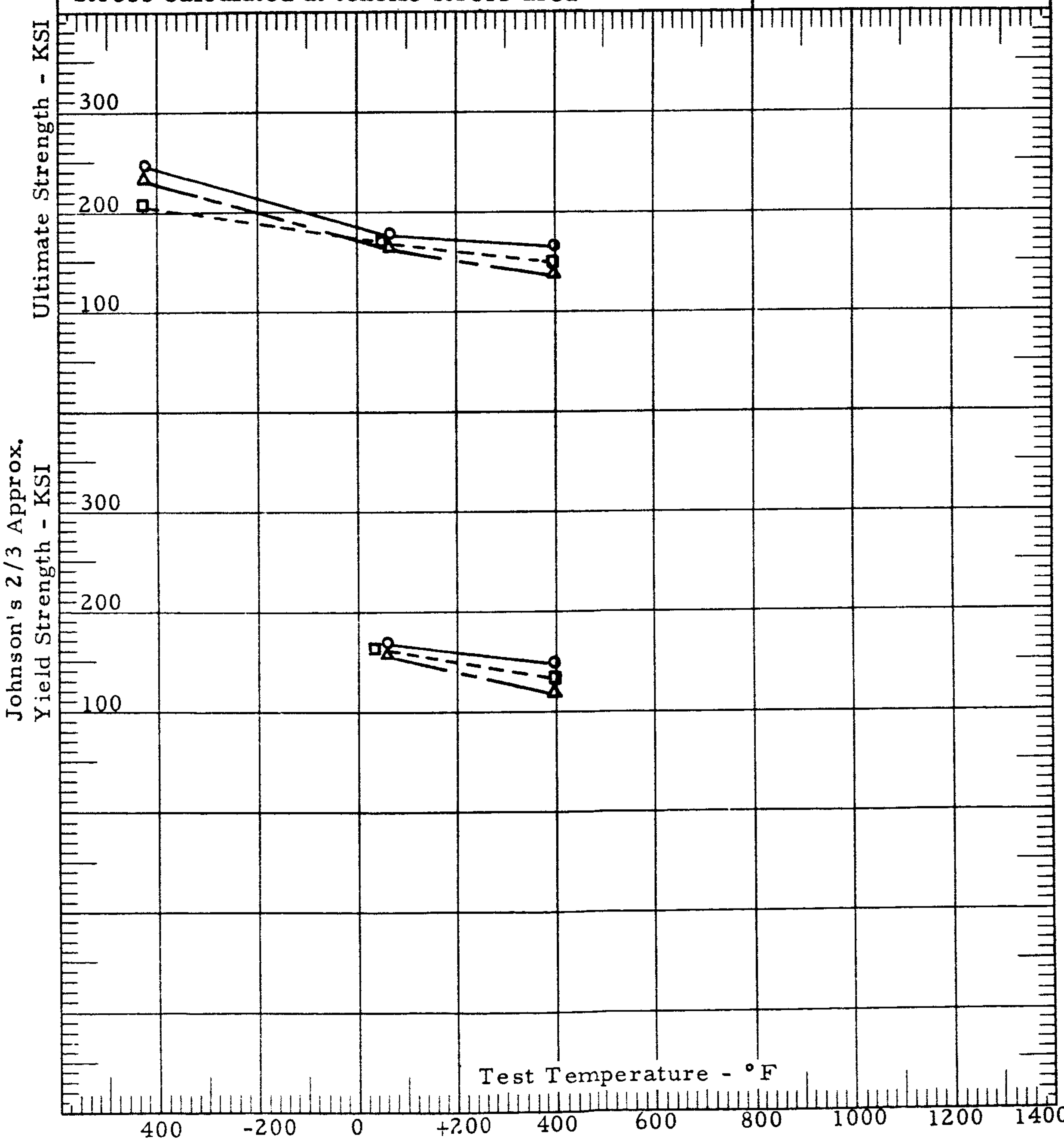
1/2-20 — — □ — —

Avg. of 3 Tests

Stress calculated at tensile stress area

Chart No.: 23

Date:



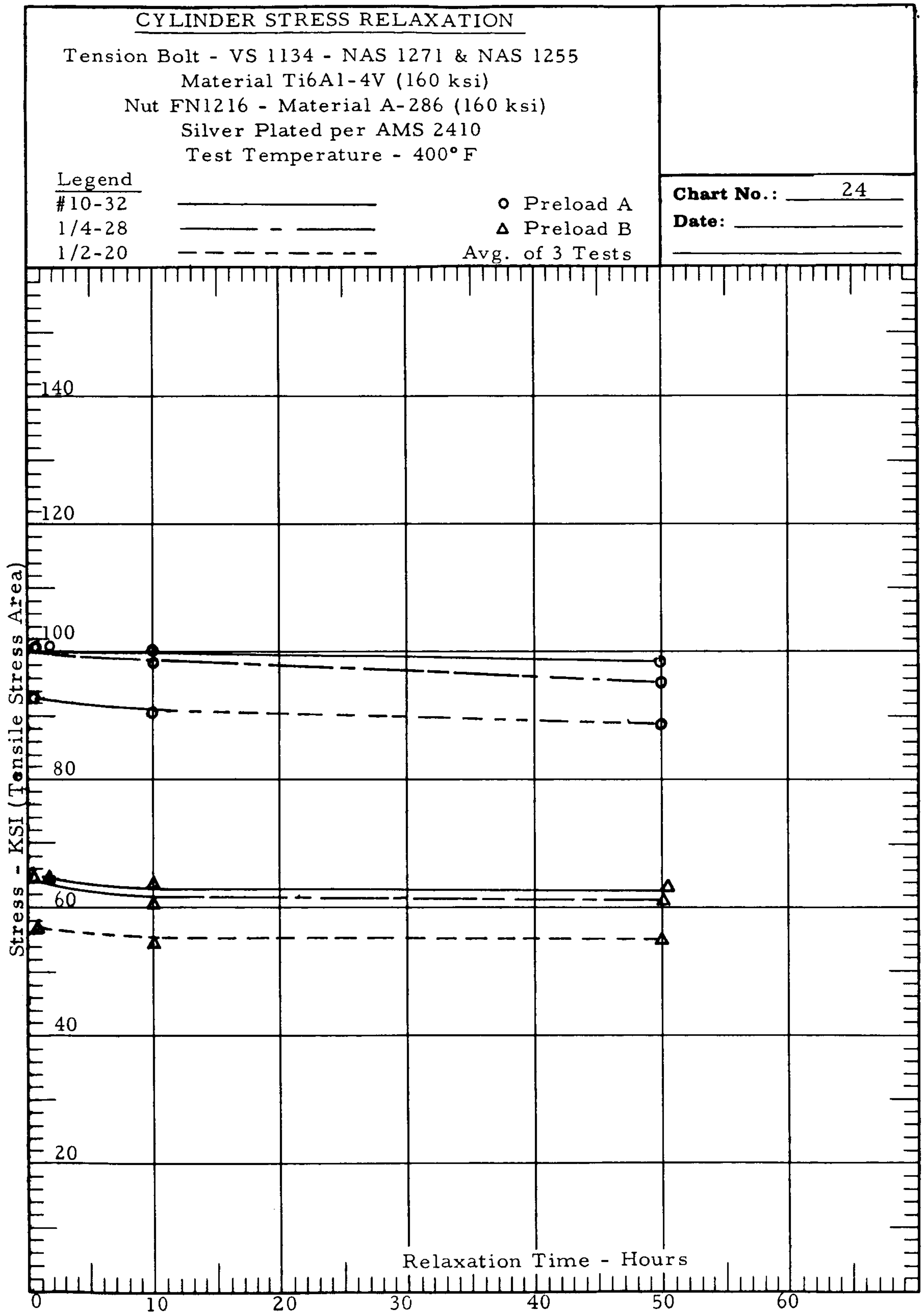

CYLINDER STRESS RELAXATION
Tension Bolt - VS 1134 - NAS 1271 & NAS 1255
Material Ti6Al-4V (160 ksi)
Nut FN1216 - Material A-286 (160 ksi)
Silver Plated per AMS 2410
Test Temperature - 400° F
Legend
#10-32
1/4-28
1/2-20
Preload A
Preload B
Avg. of 3 Tests
Chart No.: 24
Date:
Stress - KSI (Tensile Stress Area)
Relaxation Time - Hours
0
10
20
30
40
50
60
20
40
60
80
100
120
140

TABLE XIV

MECHANICAL PROPERTIES

Part No. VS 1134-3-48 - Material - Ti 6Al-4V (160 ksi)
Part No. Nut FN1216-1032 Material A-286 (160 ksi)
Size - #10-32

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	341,000	313,000	4.0	5.5
2	-423	338,000	314,000	4.0	12.0
3	-423	335,000	-	6.0	23.0
4	70	181,200	170,800	12.0	44.0
5	70	182,200	169,700	12.0	44.0
6	70	182,700	169,300	12.0	48.9
7	400	142,800	134,600	14.0	57.6
8	400	151,000	128,500	14.0	45.0
9	400	144,700	132,800	16.0	55.5

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	5,020	251,100	No Yield	
11	-423	5,350	267,600	No Yield	
12	-423	4,830	241,600	No Yield	
13	70	3,570	178,500	3,300	165,000
14	70	3,650	182,500	3,400	170,000
15	70	3,650	182,500	3,400	170,000
16	400	3,350	167,500	3,050	152,500
17	400	3,260	163,000	3,000	150,000
18	400	3,240	162,000	2,970	148,500

(1) Stress calculated at tensile stress area of .01999 square inches.

TABLE XIV (continued)

Part No. VS 1134-3-48
FN 1216-1032

1. Tensile (continued) -

Base Material Properties (As cycled)
.113 Specimens
Cycled 12 Times
Seated at 77,000 psi

70° to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
19	70	182,500	164,900	12.0	41.3
20	70	184,900	169,400	12.0	44.5
21	70	185,600	167,500	13.0	40.0

70°F to 400°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
22	70	186,300	169,500	14.0	43.0
23	70	176,800	160,000	16.0	50.0
24	70	182,500	164,900	13.0	39.0

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
25	70	3,700	185,100	3,380	169,100
26	70	3,660	183,100	3,310	165,600
27	70	3,630	181,600	3,380	169,100

70°F to 400°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
28	70	3,760	188,100	3,420	171,000
29	70	3,640	182,100	3,400	170,100
30	70	3,570	176,100	3,270	163,600

TABLE XIV (continued)

Part No. VS 1134-3-48
FN 1216-1032

1. Tensile (continued)

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
31	70	3,770	188,500	3,490	174,500
32	70	3,730	186,500	3,400	170,000
33	70	3,780	189,000	3,500	175,000
Preload B					
34	70	3,660	183,000	3,380	169,000
35	70	3,740	187,000	3,480	174,000
36	70	3,560	178,000	3,320	166,000

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
37	-423	8,900	156,900
38	-423	9,700	171,000
39	-423	9,250	163,100
40	70	5,900	104,000
41	70	5,920	104,400
42	70	5,910	104,200
43	400	4,750	83,800
44	400	4,850	85,500
45	400	4,700	82,900

TABLE XIV (continued)

Part No. VS 1134-3-48
FN 1216-1032

2. Double Shear (continued) -

"As Cycled"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
70°F to -423°F to 70°F			
46	70	5,770	101,700
47	70	5,880	103,700
48	70	5,760	101,600
70°F to 400°F to 70°F			
49	70	5,800	102,300
50	70	5,870	103,500
51	70	5,790	102,100

"As Relaxed"(50 hours)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
Preload A			
52	70	5,860	103,300
53	70	5,820	102,300
54	70	5,920	104,400
Preload B			
55	70	5,800	102,300
56	70	5,680	100,200
57	70	5,600	98,700

TABLE XIV (continued)

3. Stress Rupture

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
58	400	3,116	155,900	100	N. F.
59	400	3,116	155,900	Failed loading	
60	400	3,116	155,900	Failed loading	
61	400	3,000	150,000	135.9	N. F.
62	400	3,000	150,000	100.0	N. F.
63	400	3,000	150,000	304.7	N. F.

Testing discontinued because stress required for 100 hour life is equal to 400°F yield strength.

N. F. - No Failure

4. Stress Relaxation @ 400°F

Preload A - Initial Stress - 100,100

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
63	10	2,000	100,000
64	10	2,000	100,000
65	10	2,000	100,000
66	50	1,960	98,000
67	50	1,970	98,500
68	50	1,940	97,000

Preload B - Initial Stress - 64,500 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
69	10	1,260	63,000
70	10	1,260	63,000
71	10	1,260	63.000
72	50	1,250	62,500
73	50	1,230	61,500
74	50	1,250	62,500

TABLE XIV (continued)

Part No. VS 1134-3-48
Nut - FN 1216-1032

5. Nut Reuse and Galling Tendency -

After Soak @ -423° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
75	10	86,400	68	50	9
76	9	86,400	70	50	8
77	12	86,400	70	50	10
78	12	86,400	68	50	8
79	10	86,400	65	45	8
2nd Application					
75	15	86,400	70	50	14
76	12	86,400	70	60	13
77	13	86,400	67	50	12
78	12	86,400	65	48	12
79	12	86,400	68	48	13
3rd Application					
75	14	86,400	65	50	12
76	11	86,400	60	50	10
77	9	86,400	63	40	8
78	12	86,400	65	45	11
79	11	86,400	65	50	10
4th Application					
75	11	86,400	65	40	11
76	9	86,400	70	50	10
77	13	86,400	68	55	12
78	11	86,400	68	45	10
79	11	86,400	65	50	11
5th Application					
75	14	86,400	65	50	14
76	14	86,400	60	45	12
77	14	86,400	67	50	11
78	13	86,400	70	45	12
79	12	86,400	70	50	12

TABLE XIV (continued)

Part No. VS 1134-3-48
Nut - FN 1216-1032

5. Nut Reuse and Galling Tendency (continued)

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
80	9	86,400	55	35	5
81	11	86,400	60	40	9
82	12	86,400	60	42	8
83	8	86,400	55	38	9
84	9	86,400	55	40	8
2nd Application					
80	7	86,400	52	33	5
81	14	86,400	55	40	11
82	12	86,400	58	40	11
83	11	86,400	58	40	9
84	10	86,400	60	42	10
3rd Application					
80	8	86,400	55	35	7
81	14	86,400	60	40	12
82	13	86,400	60	45	12
83	10	86,400	65	50	10
84	14	86,400	60	45	14
4th Application					
80	14	86,400	52	30	8
81	13	86,400	58	40	12
82	15	86,400	60	40	14
83	11	86,400	62	42	11
84	14	86,400	60	40	10
5th Application					
80	8	86,400	55	35	5
81	14	86,400	60	40	11
82	14	86,400	63	40	14
83	11	86,400	60	37	12
84	12	86,400	60	40	9

TABLE XIV (continued)

Part No. VS 1134-3-48
Nut - FN 1216-10-32

5. Nut Reuse and Galling Tendency (continued)

After Soak @ 400°F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
85	11	86,400	60	55	7
86	14	86,400	60	55	10
87	12	86,400	67	65	11
88	9	86,400	55	50	7
89	8	86,400	60	60	6
2nd Application					
85	11	86,400	60	50	8
86	14	86,400	60	55	13
87	13	86,400	65	60	12
88	9	86,400	50	50	7
89	7	86,400	65	60	9
3rd Application					
85	14	86,400	60	52	12
86	19	86,400	65	55	16
87	16	86,400	65	60	14
88	10	86,400	55	55	9
89	10	86,400	70	60	9
4th Application					
85	13	86,400	60	48	9
86	16	86,400	70	55	14
87	16	86,400	68	55	14
88	9	86,400	55	50	8
89	10	86,400	70	60	9
5th Application					
85	14	86,400	60	50	12
86	12	86,400	68	55	12
87	14	86,400	68	60	13
88	8	86,400	60	52	8
89	9	86,400	65	55	8

TABLE XIV (continued)

Part No. VS 1134-3-48
Nut - FN 1216-1032

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 90 Load, pounds	Test No. 91 Load, pounds	Test No. 92 Load, pounds
25	250	600	250
50	1250	1400	1200
75	2100	2350	2300
100	3000	3150 (B.B.)	2300 (B.B.)
125	3200 (B.B.)	--	--

B.B. - Bolt Broke

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
93	10	8	30	30,000	0	No Cracks	Passed
94	11	10	30	30,000	0	No Cracks	Passed
95	15	14	30	30,000	0	No Cracks	Passed
96	15	10	30	30,000	0	No Cracks	Passed
97	13	8	30	30,000	0	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area of .01999 square inches.

(2) Stress calculated at twice nominal diameter area, .05671 square inches.

TABLE XV

MECHANICAL PROPERTIES

Part No. NAS 1271-38 - Material Ti 6Al-4V (160 ksi)
Part No. Nut FN1216-428 - Material A-286 (160 ksi)
Size - 1/4-28x2.860

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	306,200	288,000	5.0	13.6
2	-423	311,000	296,000	4.0	9.0
3	-423	308,200	294,500	5.0	12.3
4	70	168,400	160,000	12.0	49.8
5	70	168,500	162,900	10.0	51.8
6	70	166,600	159,600	10.0	51.5
7	400	136,000	127,000	16.0	58.3
8	400	136,800	128,400	14.0	58.3
9	400	133,600	125,200	12.0	59.5

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	8,920	245,300	No Yield	
11	-423	9,700	266,700	No Yield	
12	-423	8,650	237,800	No Yield	
13	70	6,750	185,500	6,125	168,400
14	70	6,475	178,000	5,500	151,200
15	70	6,500	178,700	5,600	153,900
16	400	5,100	140,200	4,125	113,400
17	400	5,350	147,000	4,600	126,400
18	400	5,350	147,000	4,750	130,600

(1) Stress calculated at tensile stress area of .03637 square inches.

TABLE XV (continued)

Part No. NAS 1271-38
FN1216-428

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	70	6,680	183,600	5,760	158,300
20	70	6,620	182,000	5,710	156,900
21	70	6,630	182,200	6,000	164,900

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	6,760	185,900	5,900	162,200
23	70	6,720	184,800	5,650	155,300
24	70	6,610	181,700	5,700	156,700

2. Double Shear

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
25	-423	14,000	142,600
26	-423	14,100	143,600
27	-423	12,900	131,400
28	70	10,900	111,000
29	70	10,750	109,500
30	70	11,000	112,000
31	400	8,000	81,500
32	400	7,900	80,500
33	400	7,500	76,400

TABLE XV (continued)

Part No. NAS 1271-38
FN 1216-428

2. Double Shear (continued) -

"As Relaxed" (50 hours)

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
34	70	10,700	109,000
35	70	10,750	109,500
36	70	10,650	108,500
Preload B			
37	70	10,300	104,900
38	70	10,500	107,000
39	70	10,700	109,000

3. Stress Rupture

Stress rupture tests at 400°F were not conducted. Fastener assembly is not rupture sensitive as evidenced by #10-32 results. The stress required for 100 hour life is equal to the 400°F yield strength.

4. Stress Relaxation @ 400°F

Preload A - Initial Stress - 100,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi(1)
40	10	3,546	97,500
41	10	3,500	96,200
42	10	3,473	95,500
43	50	3,500	96,200
44	50	3,500	96,200
45	50	3,400	93,500

TABLE XV (continued)

Part No. NAS 1271-38
FN 1216-428

4. Stress Relaxation @ 400° F (continued)

Preload B - Initial Stress - 65,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
46	10	2,250	61,900
47	10	2,250	61,900
48	10	2,218	61,000
49	50	2,200	60,500
50	50	2,250	61,900
51	50	2,218	61,000

TABLE XV (continued)

Part No. NAS 1271-38
Nut - FN 1216-428

5. Nut Reuse and Galling Tendency -

After Soak @ -423° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
52	24	86,400	130	110	18
53	24	86,400	130	100	20
54	22	86,400	130	110	16
55	25	86,400	125	105	22
56	23	86,400	125	100	18
2nd Application					
52	35	86,400	135	100	25
53	32	86,400	125	100	30
54	30	86,400	120	110	23
55	24	86,400	120	100	20
56	22	86,400	130	110	22
3rd Application					
52	28	86,400	125	90	20
53	25	86,400	130	90	16
54	33	86,400	120	100	21
55	28	86,400	125	95	21
56	15	86,400	125	90	14
4th Application					
52	22	86,400	135	90	25
53	20	86,400	130	100	28
54	26	86,400	130	100	25
55	25	86,400	125	95	22
56	24	86,400	130	100	20
5th Application					
52	32	86,400	130	90	20
53	33	86,400	130	90	25
54	30	86,400	125	95	23
55	25	86,400	120	95	23
56	32	86,400	125	95	20

TABLE XV (continued)

Part No. NAS 1271-38
Nut - FN 1216-428

5. Nut Reuse and Galling Tendency (continued)

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
57	20	86,400	130	100	11
58	22	86,400	130	100	14
59	23	86,400	130	95	20
60	24	86,400	125	90	16
61	20	86,400	125	95	14
2nd Application					
57	14	86,400	125	85	10
58	22	86,400	125	95	18
59	23	86,400	125	90	22
60	24	86,400	125	85	20
61	22	86,400	120	90	18
3rd Application					
57	14	86,400	120	90	12
58	24	86,400	140	100	21
59	21	86,400	120	95	22
60	26	86,400	130	90	24
61	25	86,400	125	90	18
4th Application					
57	14	86,400	110	80	10
58	26	86,400	145	110	24
59	20	86,400	130	100	18
60	26	86,400	125	90	25
61	24	86,400	120	85	19
5th Application					
57	13	86,400	110	80	12
58	24	86,400	140	105	24
59	20	86,400	135	100	22
60	26	86,400	125	95	26
61	20	86,400	125	90	22

TABLE XV (continued)

Part No. NAS 1271-38
Nut - FN 1216-428

5. Nut Reuse and Galling Tendency (continued)

After Soak at 400° F

Test No.	Maximum Installation inch-pounds	Seated Stress psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
62	24	86,400	125	115	16
63	26	86,400	130	120	20
64	26	86,400	130	115	14
65	24	86,400	130	120	16
66	25	86,400	135	120	20
2nd Application					
62	22	86,400	125	110	18
63	24	86,400	130	105	22
64	20	86,400	130	100	16
65	25	86,400	135	110	20
66	27	86,400	135	120	22
3rd Application					
62	24	86,400	130	100	18
63	25	86,400	130	100	22
64	21	86,400	130	100	20
65	26	86,400	135	110	22
66	24	86,400	130	110	20
4th Application					
62	20	86,400	130	110	18
63	24	86,400	125	110	22
64	23	86,400	130	110	20
65	24	86,400	135	120	20
66	22	86,400	130	115	27
5th Application					
62	22	86,400	130	110	12
63	24	86,400	130	110	20
64	25	86,400	130	120	16
65	24	86,400	135	110	14
66	22	86,400	130	110	22

TABLE XV (continued)

Part No. NAS 1271-38
Nut - FN 1216-428

6. Torque vs. Induced Load @ Room Temperature -

Torque, inch-pounds	Test No. 67 Load, pounds	Test No. 68 Load, pounds	Test No. 69 Load, pounds
50	850	550	750
75	1200	--	1250
100	2050	1700	1750
125	2450	2150	2350
150	3350	2750	2900
175	4050	3300	3400
200	4700	4050	4150
225	5300	4750	4950
250	5600	5400	5450
275	Bolt Broke	Bolt Broke	Bolt Broke

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
70	15	10	60	30,000	0	No Cracks	Passed
71	18	12	60	30,000	0	No Cracks	Passed
72	12	8	60	30,000	60	No Cracks	Passed
73	15	10	60	30,000	0	No Cracks	Passed
74	13	10	60	30,000	0	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area of .03637 square inches.

(2) Stress calculated at twice nominal diameter area .09817 square inches.

TABLE XVI

MECHANICAL PROPERTIES

Part No. NAS 1275-48 - Material - Ti 6Al-4V (160 ksi)
Part No. Nut FN 1216-820 - Material A-286 (160 ksi)
Size 1/2-20x3.741

1. Tensile - Base Material Properties (As Received)

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	281,400	281,400	3.6	17.5
2	-423	277,400	274,400	4.3	24.3
3	-423	276,100	263,700	2.9	17.9
4	70	170,800	158,700	14.2	49.6
5	70	171,700	160,500	14.2	52.9
6	70	169,700	155,400	14.2	51.3
7	400	139,500	121,000	16.4	63.6
8	400	141,500	123,300	17.8	64.4
9	400	141,500	128,500	15.0	64.7

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	32,500	203,000	No Yield	
11	-423	37,800	236,000	No Yield	
12	-423	32,400	202,200	No Yield	
13	70	29,500	184,400	26,900	168,200
14	70	29,700	185,700	27,000	168,800
15	70	29,600	185,100	26,700	166,900
16	400	25,000	156,300	22,750	142,200
17	400	24,400	152,500	22,500	140,700
18	400	24,400	152,500	22,200	138,800

(1) Stress calculated at tensile stress area of .03637 square inches.

TABLE XVI (continued)

Part No. NAS 1275-48
FN 1216-820

1. Tensile (continued) -

Base Material Properties (As cycled)
.357 Specimens
Cycled 12 Times
Seated at 77,000 psi

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 400°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, 1.4 in. %	Red. of Area, %
19	70	171,800	161,700	17.1	56.9
20	70	171,800	162,700	13.5	56.0
21	70	170,800	161,700	13.5	54.8

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 400°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	28,900	180,700	26,800	167,600
23	70	29,800	186,400	26,700	168,200
24	70	27,400	171,400	27,300	170,700

TABLE XVI (continued)

Part No. NAS 1275-48
FN 1216-820

1. Tensile (continued) -

As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
25	70	28,500	178,200	27,500	172,000
26	70	27,500	171,900	27,000	168,900
27	70	27,000	168,800	26,000	162,600

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
28	70	27,600	172,600	25,750	161,000
29	70	26,800	167,600	25,500	159,500
30	70	27,700	173,200	26,000	162,600

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
	-423	Tests not conducted. Shear fixtures being redesigned.	
31	70	43,200	110,000
32	70	43,600	111,000
33	70	42,500	108,200
34	400	34,400	87,500
35	400	35,300	89,700
36	400	34,200	87,000

TABLE XVI (continued)

Part No. NAS 1275-48
FN 1216-820

2. Double Shear -

"As Cycled"

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 400°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
37	70	41,700	106,200
38	70	41,000	104,400
39	70	40,900	104,200

As Relaxed - 50 Hours

Preload A

40	70	42,300	107,700
41	70	41,800	106,400
42	70	41,900	106,700

Preload B

43	70	41,100	104,700
44	70	42,500	108,200
45	70	42,700	108,700

(2) Stress calculated at twice nominal dia., .3927 square inches.

3. Stress Rupture -

Stress rupture tests at 400°F were not conducted. Fastener assembly is not considered to be rupture sensitive as evidenced by 10-32 results. The stress required for 100 hour life was equal to the 400°F yeild strength.

TABLE XVI (continued)

Part No. NAS 1275-48
FN 1216-820

4. Stress Relaxation @400° F -

Preload A - Initial Stress - 93, 100 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
46	10	14,600	91,300
47	10	14,310	89,500
48	10	14,486	90,600
49	50	14,183	88,200
50	50	14,183	88,700
51	50	14,183	88,700

Preload B - Initial Stress - 57,500 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
52	10	8,986	56,200
53	10	8,890	55,600
54	10	8,890	55,600
55	50	8,986	56,200
56	50	8,890	55,600
57	50	8,890	55,600

TABLE XVI (continued)

Part No. NAS 1275-48
Nut - FN 1216-820 - Coated with SPS K_2 MoS_2

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
58	50	86,400	800	625	60
59	30	86,400	725	600	35
60	60	86,400	750	575	65
61	55	86,400	825	625	60
62	35	86,400	800	600	35
2nd Application					
58	45	86,400	825	600	60
59	30	86,400	700	550	35
60	40	86,400	750	575	55
61	40	86,400	850	650	55
62	25	86,400	775	625	30
3rd Application					
58	50	86,400	825	600	60
59	35	96,400	700	550	40
60	45	86,400	725	600	60
61	40	86,400	800	650	55
62	25	86,400	750	625	35
4th Application					
58	50	86,400	800	600	60
59	35	86,400	750	550	40
60	45	86,400	725	575	60
61	40	86,400	825	625	50
62	20	86,400	750	625	30
5th Application					
58	50	86,400	800	650	65
59	30	86,400	725	550	40
60	50	86,400	725	600	60
61	40	86,400	800	650	45
62	25	86,400	825	600	30

TABLE XVI (continued)

Part No. NAS 1275-48
Nut - FN 1216-820 - Coated with SPS K2 MoS_2

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 400°F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
63	30	86,400	750	700	25
64	38	86,400	640	700	30
65	70	86,400	800	800	50
66	65	86,400	825	800	50
67	70	86,400	850	825	50
2nd Application					
63	25	86,400	750	600	18
64	30	86,400	760	600	30
65	40	86,400	800	700	35
66	45	86,400	800	700	50
67	45	86,400	800	700	40
3rd Application					
63	23	86,400	740	600	18
64	30	86,400	725	550	45
65	35	86,400	825	700	40
66	45	86,400	775	650	50
67	35	86,400	800	700	45
4th Application					
63	23	86,400	750	600	20
64	55	86,400	700	675	45
65	40	86,400	800	725	45
66	65	86,400	800	750	70
67	50	86,500	850	750	55
5th Application					
63	20	86,400	725	600	18
64	60	86,400	725	500	55
65	45	86,400	775	675	40
66	65	86,400	800	650	50
67	50	86,400	825	650	45

TABLE XVI (continued)

Part No. NAS 1275-48
Nut - FN 1216-820

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 68 Load, pounds	Test No. 69 Load, pounds	Test No. 70 Load, pounds
400	3,700	3,750	3,750
800	8,500	9,500	9,500
1200	13,500	15,500	15,000
1600	21,000	21,500	20,500
2000	25,000	25,000	25,000
2400	Bolt Broke		

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
71	120	150	300	30,000	0	No Cracks	Passed
72	135	145	300	30,000	0	No Cracks	Passed
73	125	150	300	30,000	0	No Cracks	Passed
74	130	140	300	30,000	0	No Cracks	Passed
75	125	125	300	30,000	0	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area of .1599 square inches.

(2) Stress calculated at twice nominal diameter area, .3927 square inches.

TABLE XVII

SUMMARY OF RESULTS

VS2502 & VN466B - MATERIAL A-286 (200 KSI)

Material Properties -

Test Temp.	U. T. S. - KSI #10	U. T. S. - KSI 1/4	U. T. S. - KSI 1/2	0.2 % Offset Yield - KSI #10	0.2 % Offset Yield - KSI 1/4	0.2 % Offset Yield - KSI 1/2	Elongation - % #10	Elongation - % 1/4	Elongation - % 1/2
-423°F	273.5	282.7	251.8	198.0	219.0	208.1	22.0	17.0	11.4
	275.0	277.0	238.1	237.5	221.0	213.1	22.0	20.0	13.6
	274.0	281.5	250.8	220.0	218.5	202.2	18.0	17.0	15.7
70°F	195.8	195.0	195.9	184.3	177.5	154.7	12.0	12.0	14.2
	191.8	199.0	195.9	177.5	184.5	155.7	12.0	12.0	14.2
	196.4	198.0	196.9	182.6	182.5	155.7	12.0	12.0	15.0
1200°F	121.0	134.6	142.5	120.0	132.6	137.5	8.0	6.0	11.4
	142.0	138.0	141.5	139.0	134.3	137.5	8.0	6.0	11.4
	144.0	140.0	145.0	141.0	138.0	142.5	8.0	10.0	9.3

Test Temp.	Reduction of Area - % #10	Reduction of Area - % 1/4	Reduction of Area - % 1/2	Shear Strength - KSI #10	Shear Strength - KSI 1/4	Shear Strength - KSI 1/2
-423°F	39.7	38.5	36.0	163.1	154.8	145.0
	39.4	33.0	37.3	162.9	156.9	140.5
	39.4	35.8	37.5	179.9	165.0	145.0
70°F	40.0	43.5	39.7	120.6	116.6	118.9
	42.4	41.8	38.1	122.4	113.6	118.4
	42.4	41.5	38.5	121.3	117.7	117.6
1200°F	42.1	15.3	37.3	75.8	74.4	82.7
	40.8	22.0	58.8	76.3	75.4	82.7
	39.5	40.8	56.7	75.4	75.4	85.5

Bolt & Nut Properties -

Test Temp.	U. T. S. - KSI(1) #10	U. T. S. - KSI(1) 1/4	U. T. S. - KSI(1) 1/2	Johnson's 2/3 Approx. Yield - KSI #10	Johnson's 2/3 Approx. Yield - KSI 1/4	Johnson's 2/3 Approx. Yield - KSI 1/2
-423°F	287.0	294.2	272.0	195.0	231.0	202.0
	290.0	291.4	268.0	230.0	217.2	206.0
	291.0	288.7	272.0	224.0	211.7	205.0
70°F	214.1	216.1	218.8	165.1	163.5	150.0
	212.6	213.3	217.0	160.1	156.7	150.0
	214.1	213.9	217.0	157.6	158.3	151.9
1200°F	177.5	153.9	166.0	164.0	140.9	143.5
	180.0	161.5	166.5	167.5	145.7	148.0
	180.0	158.0	164.5	165.0	145.7	145.5

(1) Stress calculated at tensile stress area

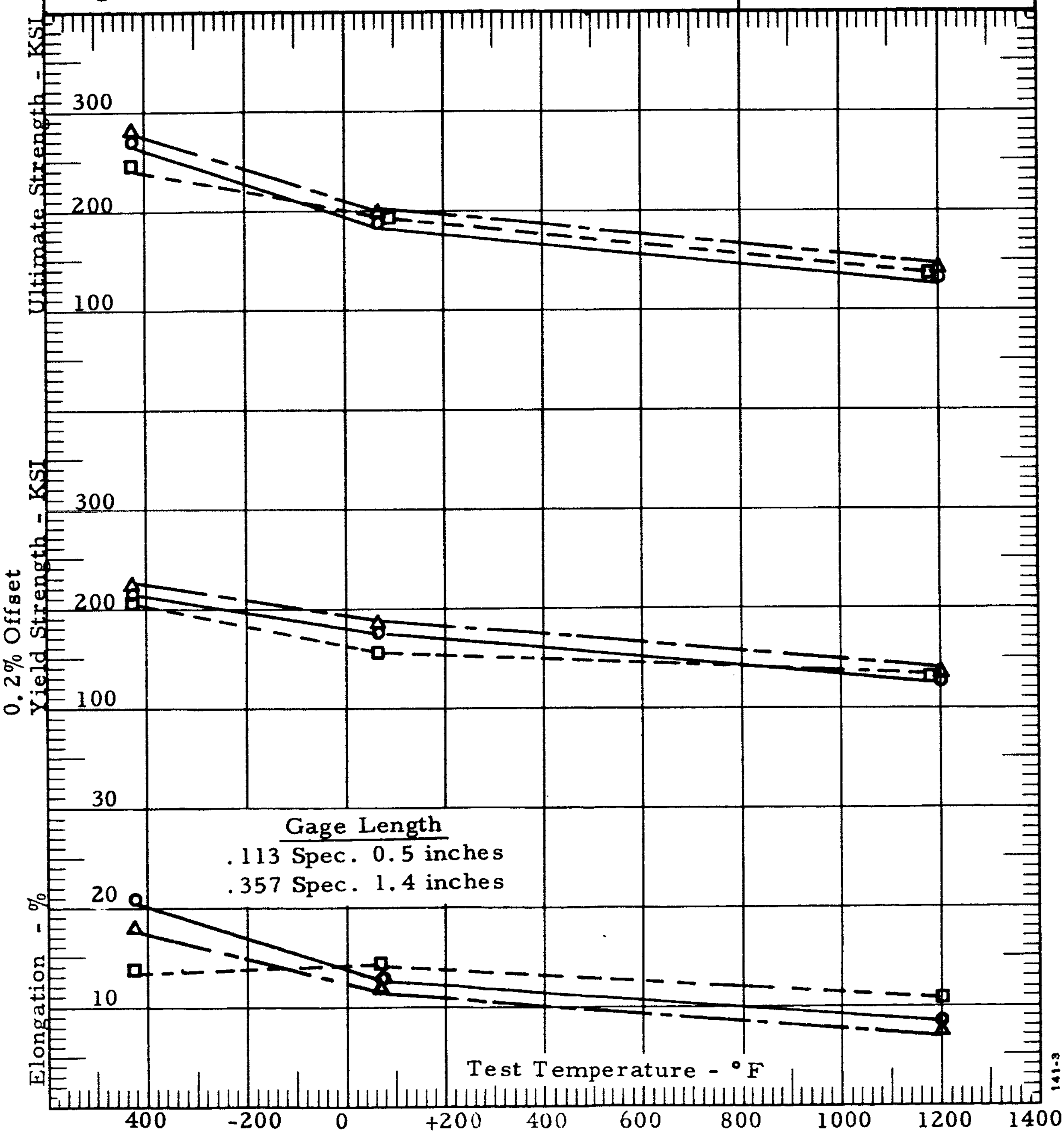
MATERIAL PROPERTIES

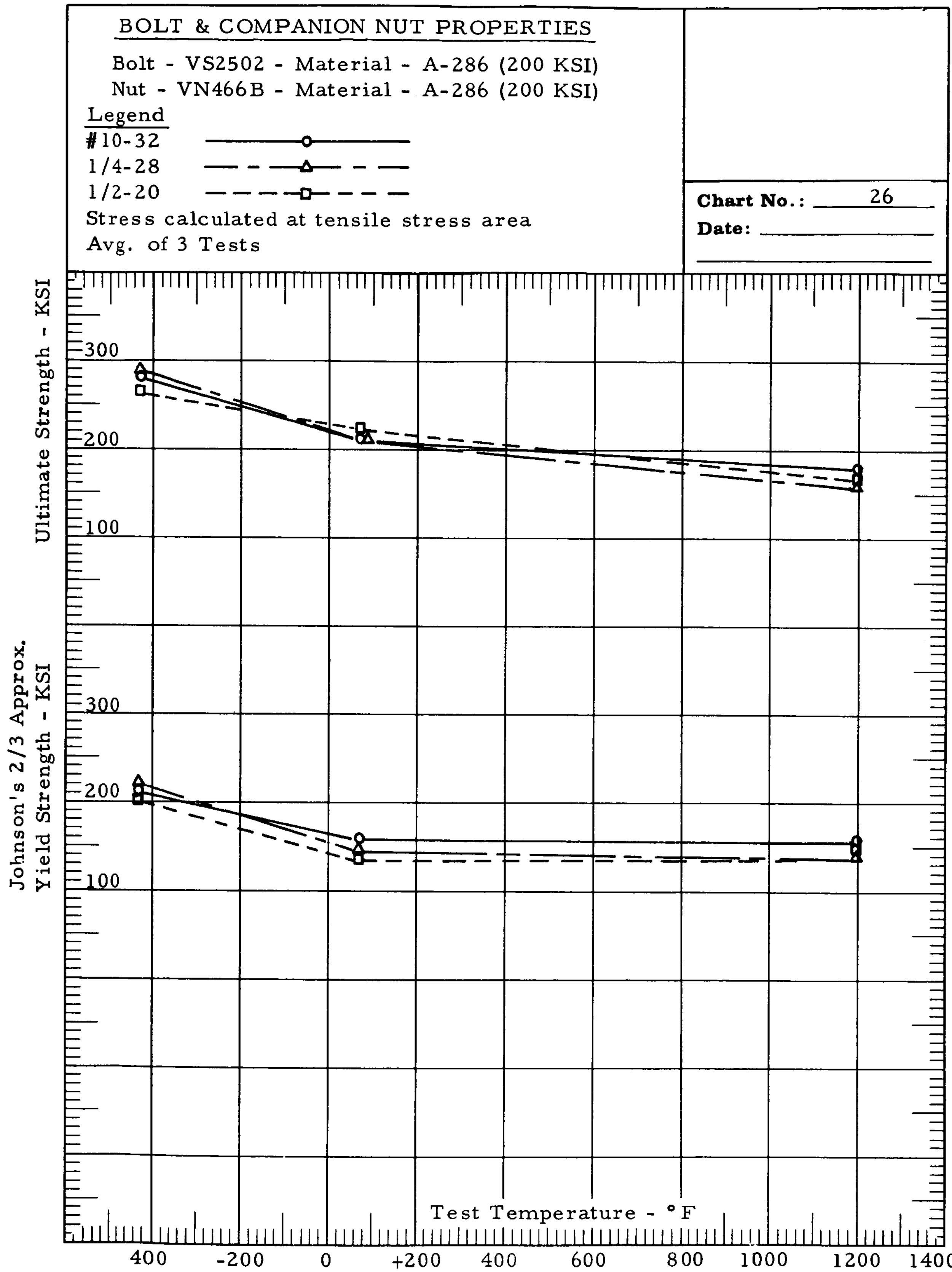
Tension Bolt - VS 2502
Material - A-286 (200 KSI)

Legend
#10 (.113 Spec.)
1/4 (.113 Spec.)
1/2 (.357 Spec.)

Avg. of 3 Tests

Chart No.: 25
Date:




BOLT & COMPANION NUT PROPERTIES
Bolt - VS2502 - Material - A-286 (200 KSI)
Nut - VN466B - Material - A-286 (200 KSI)
Legend
#10-32
1/4-28
1/2-20
Stress calculated at tensile stress area
Avg. of 3 Tests
Chart No.: 26
Date:
Ultimate Strength - KSI
Johnson's 2/3 Approx.
Yield Strength - KSI
300
200
100
300
200
100
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3

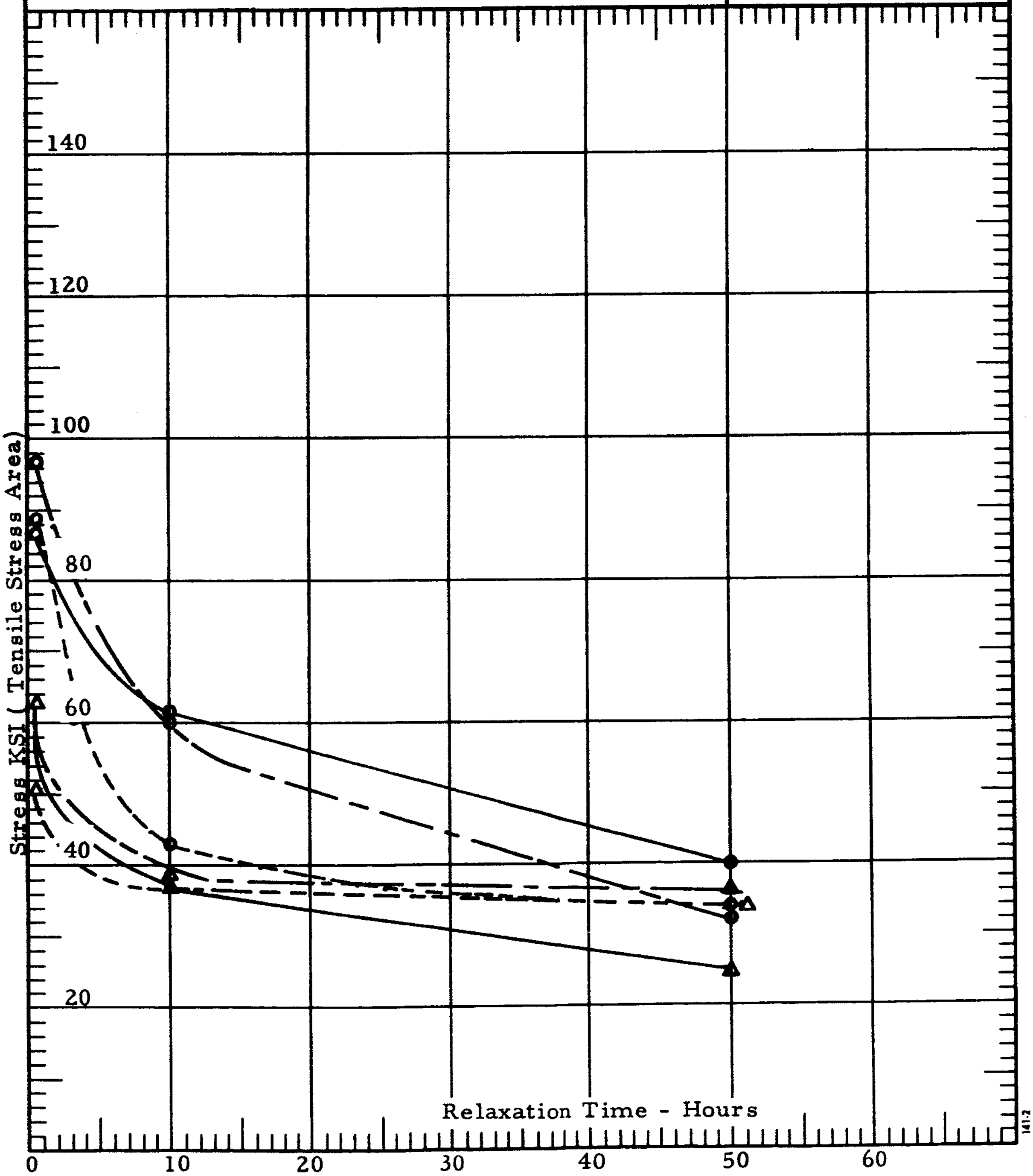
CYLINDER STRESS RELAXATION

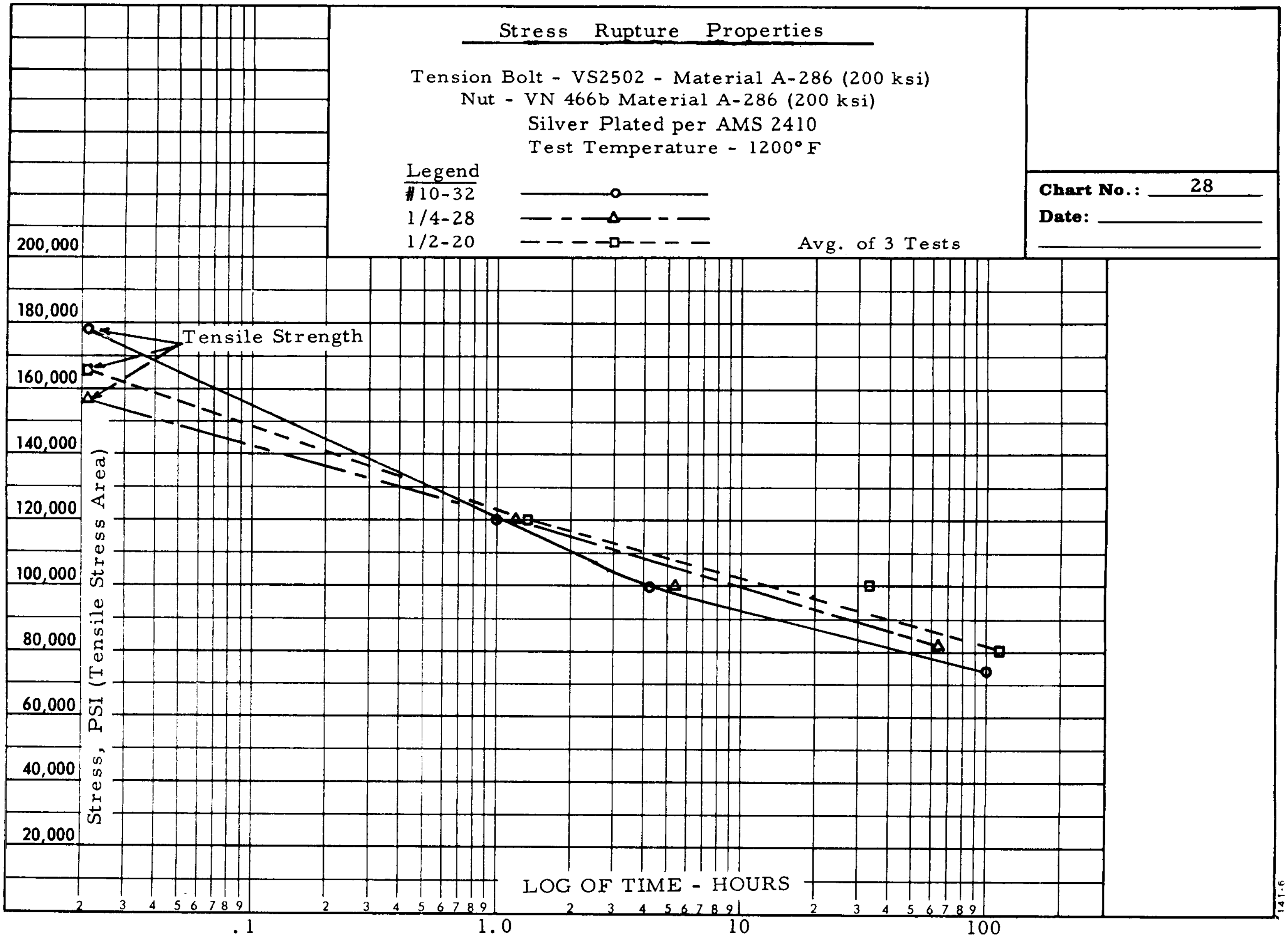
Tension Bolt - VS2502 - Material A-286 (200 ksi)
Nut - VN 466B - Material A-286 (200 ksi)
Silver Plated per AMS 2410
Test Temperature - 1200° F

Legend
#10-32 ————————
1/4-28 ——— — ———
1/2-20 — — — — — —

o Preload A
Δ Preload B
Avg. of 3 Tests

Chart No.: 27
Date:





Stress Rupture Properties
Tension Bolt - VS2502 - Material A-286 (200 ksi)
Nut - VN 466b Material A-286 (200 ksi)
Silver Plated per AMS 2410
Test Temperature - 1200° F
Legend
#10-32
1/4-28
1/2-20
Avg. of 3 Tests
Chart No.: 28
Date:
Tensile Strength
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
Stress, PSI (Tensile Stress Area)
LOG OF TIME - HOURS
.1
1.0
10
100
141-6

TABLE XVIII

MECHANICAL PROPERTIES

Part No. VS 2502-3-40 Material A-286 (200 ksi)
Part No. Nut VN 466-B-02 Material A-286 (200 ksi)
Size - #10-32

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	273,500	198,000	22.0	39.7
2	-423	275,000	237,500	22.0	39.4
3	-423	274,000	220,000	18.0	39.4
4	70	195,800	184,300	12.0	40.0
5	70	191,800	177,500	12.0	42.4
6	70	196,400	182,600	12.0	42.4
7	1200	121,000	120,000	8.0	42.1
8	1200	142,000	139,000	8.0	40.8
9	1200	144,000	141,000	8.0	39.5

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	5,860	287,000	3,900	195,200
11	-423	5,800	290,000	4,600	230,000
12	-423	5,820	291,000	4,475	224,000
13	70	4,280	214,100	3,300	165,100
14	70	4,250	212,600	3,200	160,100
15	70	4,280	214,100	3,150	157,600
16	1200	3,550	177,500	3,280	164,000
17	1200	3,600	180,000	3,350	167,500
18	1200	3,600	180,000	3,300	165,000

(1) Stress calculated at tensile stress area of .01999 square inches.

TABLE XVIII (continued)

Part No. VS 2502-3-40
VN466-B-02

1. Tensile (continued) -

Base Material Properties (As Cycled)
.113 Specimens
Cycled 12 Times
Seated at 104,000 psi

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
19	70	196,800	176,300	15.0	42.0
20	70	200,000	178,900	11.0	40.0
21	70	193,700	174,700	12.0	40.3

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
22 (a)	70	186,200	158,100	10.0	35.5
23 (a)	70	196,400	163,200	12.0	41.1
24 (b)	70	198,900	176,000	10.0	35.5
25 (b)	70	187,600	159,200	10.0	32.2

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
26	70	4,240	212,100	3,400	170,100
27	70	4,280	214,100	3,210	160,600
28	70	4,240	212,100	3,300	165,100

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
29 (a)	70	4,160	208,100	3,100	155,000
30 (a)	70	4,250	212,600	3,200	160,000
31 (b)	70	4,290	214,600	3,550	177,500
32 (b)	70	4,150	207,600	3,150	157,500
33 (b)	70	4,270	213,600	3,450	172,500

(a) Fast Cycle
(b) Slow Cycle

TABLE XVIII (continued)

Part No. VS 2502-3-40
VN 466-B-02

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
34	70	3,990	199,600	3,150	157,600
35	70	4,060	203,100	3,160	158,100
36	70	4,100	205,100	3,240	162,000

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
37	70	4,100	205,100	3,160	158,100
38	70	4,080	204,100	3,070	153,600
39	70	4,190	209,600	3,250	162,600

2. Double Shear

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
40	-423	9,250	163,100
41	-423	9,240	162,900
42	-423	10,200	179,900
43	70	6,160	108,600
44	70	6,140	108,300
45	70	6,160	108,600
46	1200	4,300	75,800
47	1200	4,325	76,300
48	1200	4,275	75,400

(2) Stress calculated at twice nominal dia, area, .05671 square inches.

TABLE XVIII (continued)

Part No. VS 2502-3-40
VN 466-B-02

2. Double Shear -

"As Cycled"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
70°F to -423°F to 70°F			
49	70	6,160	108,600
50	70	6,160	108,600
51	70	6,180	109,000
70°F to 1200°F to 70°F			
52 (a)	70	6,060	106,900
53 (a)	70	6,030	106,300
54 (b)	70	6,020	106,200
55 (b)	70	5,980	105,400
56 (b)	70	6,060	106,900
		As Relaxed - 50 Hours	
Preload A			
57	70	6,050	106,700
58	70	6,030	106,300
59	70	6,030	106,300
Preload B			
60	70	6,000	105,800
61	70	5,930	104,600
62	70	5,900	104,000

TABLE XVIII (continued)

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
63	1200	1,500	75,000	65.2	T
64	1200	1,500	75,000	145.2	N. F.
65	1200	1,500	75,000	89.9	N. F.
66	1200	2,000	100,000	2.4	T
67	1200	2,000	100,000	2.4	T
68	1200	2,000	100,000	7.6	T
69	1200	2,400	120,000	.4	T
70	1200	2,400	120,000	.6	T
71	1200	2,400	120,000	1.3	T

4. Stress Relaxation @ 1200°F -

Preload A - Initial Stress - 86,000 psi

Test No.	Hours Run	Residual Stress Pounds	psi(1)
72	10	Bolt fractured when disassembled	
73	10	Bolt fractured when disassembled	
74	10	Bolt fractured when disassembled	
75	50	829	41,500
76	50	720	36,000
77	50	880	44,000

Preload B - Initial Stress - 62,000 psi

Test No.	Hours Run	Residual Stress Pounds	psi(1)
78	10	740	37,000
79	10	770	38,500
80	10	770	38,500
81	50	460	23,000
82	50	530	26,500
83	50	530	26,500

TABLE XVIII (continued)

Part No. VS 2502-3-40
Nut VN 466-B-02

5. Nut Reuse and Galling Tendency -

After Soak @ -423° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
84	10	108,000	110	85	6
85	9	108,000	120	80	7
86	12	108,000	130	80	8
87	8	108,000	130	100	6
2nd Application					
84	8	108,000	115	80	6
85	5	108,000	130	80	6
86	8	108,000	120	100	6
87	5	108,000	125	110	4
3rd Application					
84	8	108,000	115	80	6
85	5	108,000	130	80	6
86	8	108,000	120	100	6
87	5	108,000	125	110	4
4th Application					
84	10	108,000	125	80	7
85	6	108,000	135	80	6
86	8	108,000	115	100	8
87	6	108,000	135	130	5
5th Application					
84	10	108,000	115 B.B.	--	--
85	6	108,000	110 B.B.	--	--
86	8	108,000	135	115	7
87	6	108,000	135	120	6

B.B. - Bolt broke

TABLE XVIII (continued)

Part No. VS 2502-3-40
Nut VN 466-B-02

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
88	11	108,000	80	60	6
89	13	108,000	75	55	8
90	12	108,000	75	55	8
91	10	108,000	85	62	6
92	13	108,000	80	58	7
2nd Application					
88	8	108,000	85	65	6
89	7	108,000	85	55	6
90	8	108,000	80	55	7
91	8	108,000	95	70	6
92	8	108,000	85	60	7
3rd Application					
88	9	108,000	90	60	7
89	7	108,000	85	55	6
90	8	108,000	85	55	7
91	8	108,000	105	85	6
92	7	108,000	80	70	6
4th Application					
88	8	108,000	90	65	9
89	7	108,000	90	60	7
90	9	108,000	90	60	8
91	7	108,000	115	95	7
92	6	108,000	90	55	6
5th Application					
88	11	108,000	95	70	10
89	8	108,000	90	60	8
90	9	108,000	90	62	8
91	9	108,000	105	95	8
92	6	108,000	90	65	6

TABLE XVIII (continued)

Part No. VS 2502-3-40
Nut VN 466-B-02

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 1200° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
93	11	108,000	90	225	Bolt broke
94	10	108,000	80	210	"
95	12	108,000	85	225	"
96	13	108,000	90	240	"
97	10	108,000	90	225	"

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 98 Load, pounds	Test No. 99 Load, pounds	Test No. 100 Load, pounds
25	650	600	650
50	1400	1500	1500
75	2450	2700	2550
100	3100	3400	3150
125	3500	Yield	3750
150	B.B.	--	Yield

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
101	13	6	30	30,000	5°	No Cracks	Passed
102	10	4	30	30,000	20°	No Cracks	Passed
103	12	6	30	30,000	45°	No Cracks	Passed
104	9	5	30	30,000	15°	No Cracks	Passed
105	12	7	30	30,000	0°	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area of .1999 square inches.
(2) Stress calculated at twice nominal diameter area, .05671 square inches.
B.B. Bolt Broke

TABLE XIX

MECHANICAL PROPERTIES

Part No. VS 2502-4-44 - Material A-286 (200 ksi)
Part No. Nut VN 466-B-048 - Material A-286 (200 ksi)
Size - 1/4-28

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	282,000	219,000	17.0	38.5
2	-423	277,000	221,000	20.0	33.0
3	-423	281,500	218,500	17.0	35.8
4	70	195,000	177,500	12.0	43.5
5	70	199,000	184,500	12.0	41.8
6	70	198,000	182,500	12.0	41.5
7	1200	134,600	132,600	6.0	15.3
8	1200	138,000	134,300	6.0	22.0
9	1200	140,000	138,000	10.0	-

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	10,700	294,200	8,400	231,000
11	-423	10,600	291,400	7,900	217,200
12	-423	10,500	288,700	7,700	211,700
13	70	7,860	216,100	5,950	163,500
14	70	7,760	213,300	5,700	156,700
15	70	7,780	213,900	5,760	158,300
16	1200	5,600	153,900	5,125	140,900
17	1200	5,875	161,500	5,300	145,700
18	1200	5,750	158,000	5,300	145,700

(1) Stress calculated at tensile stress area of .03637 square inches.

TABLE XIX (continued)

Part No. VS 2502-4-44
VN 466-B-048

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	70	7,450	204,800	5,810	159,700
20	70	7,250	199,300	5,720	157,700
21	70	Specimen was damaged in disassembly			

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	7,780	213,900	6,380	175,400
23	70	7,650	210,300	6,510	178,900
24	70	7,620	209,500	5,940	163,300

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
25	-423	15,200	154,800
26	-423	15,400	156,900
27	-423	16,200	165,000
28	70	11,450	116,600
29	70	11,150	113,600
30	70	11,550	117,700
31	1200	7,300	74,400
32	1200	7,400	75,400
33	1200	7,400	75,400

TABLE XIX (continued)

Part No. VS 2502-4-44
VN 466-B-048

2. Double Shear (continued) -

As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
34	70	11,300	115,100
35	70	11,350	115,600
36	70	Specimen was damaged in disassembly	

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
37	70	11,500	117,100
38	70	11,700	119,000
39	70	11,600	118,200

(2) Stress calculated at twice nominal dia., .09817 square inches.

TABLE XIX (continued)

Part No. VS 2502-4-44
VN 466-B-048

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
40	1200	2,910	80,000	63.6	T
41	1200	2,910	80,000	64.2	T
42	1200	2,910	80,000	133.0	T
43	1200	3,637	100,000	6.0	T
44	1200	3,637	100,000	6.4	T
45	1200	3,637	100,000	6.3	T
46	1200	4,364	120,000	.4	T
47	1200	4,364	120,000	3.6	T
48	1200	4,364	120,000	.1	T

4. Stress Relaxation @ 1200°F -

Preload A - Initial Stress - 97,600 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
49	10	2,182	60,000
50	10	2,200	60,500
51	10	Specimen damaged in disassembly	
52	50	1,149	31,600
53	50	1,149	31,600
54	50	1,149	31,600

Preload B - Initial Stress - 62,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
55	10	1,400	38,500
56	10	1,338	36,800
57	10	1,552	42,700
58	50	1,360	37,400
59	50	1,360	37,400
60	50	1,360	37,400

TABLE XIX (continued)

Part No. VS 2502-4-44
Nut VN 466-B-048

5. Nut Reuse and Galling Tendency -

After Soak @ -423° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
61	10	108,000	260	200	6
62	14	108,000	260	175	10
63	12	108,000	250	200	10
64	18	108,000	250	200	11
65	12	108,000	250	210	8
2nd Application					
61	3	108,000	245	160	3
62	6	108,000	250	175	8
63	7	108,000	235	160	8
64	9	108,000	245	160	11
65	8	108,000	240	200	8
3rd Application					
61	4	108,000	240	180	4
62	6	108,000	230	190	8
63	7	108,000	240	180	10
64	9	108,000	230	190	11
65	8	108,000	235	210	8
4th Application					
61	3	108,000	240	200	3
62	8	108,000	235	160	7
63	6	108,000	245	180	10
64	10	108,000	240	175	10
65	8	108,000	240	175	8
5th Application					
61	3	108,000	235	175	4
62	9	108,000	230	200	8
63	6	108,000	240	185	8
64	10	108,000	235	190	10
65	7	108,000	235	215	8

TABLE XIX (continued)

Part No. VS 2502-4-44
Nut VN 466-B-048

5. Nut Reuse and Galling Tendency (continued)-

After Soak @ 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
66	14	108,000	180	130	9
67	13	108,000	185	140	6
68	11	108,000	165	120	8
69	15	108,000	205	165	10
70	13	108,000	165	130	8
2nd Application					
66	9	108,000	185	140	9
67	7	108,000	200	150	6
68	8	108,000	180	120	7
69	10	108,000	205	150	10
70	9	108,000	190	135	8
3rd Application					
66	9	108,000	210	170	8
67	7	108,000	210	160	4
68	8	108,000	200	160	8
69	8	108,000	200	160	8
70	9	108,000	200	140	8
4th Application					
66	9	108,000	210	165	9
67	6	108,000	200	160	7
68	7	108,000	180	140	8
69	10	108,000	200	140	8
70	10	108,000	210	140	8
5th Application					
66	8	108,000	195	170	8
67	6	108,000	205	160	6
68	7	108,000	180	140	8
69	8	108,000	200	160	7
70	9	108,000	190	150	6

TABLE XIX (continued)

Part No. VS 2502-4-44
Nut VN 466-B-048

5. Nut Reuse and Galling Tendency (continued) -

After Soak @ 1200° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
71	14	108,000	190	450	Bolt broke
72	18	108,000	170	425	"
73	15	108,000	190	475	"
74	12	108,000	185	425	"
75	11	108,000	155	500	"

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 76 Load, pounds	Test No. 77 Load, pounds	Test No. 78 Load, pounds
25	300	250	350
50	900	850	1150
75	1500	1550	1750
100	2000	2000	2250
125	2500	2550	2900
150	3150	3250	3200
175	3700	3800	4050
200	4100	4300	4650
225	4800	4800	5150
250	5450	5500	5700
275	6150	6100	6300
300	6650	6500	6650

TABLE XIX (continued)

Part No. VS 2502-4-44
Nut VN 466-B-048

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
79	10	15	60	30,000	0	No Cracks	Passed
80	10	15	60	30,000	0	No Cracks	Passed
81	10	15	60	30,000	0	No Cracks	Passed
82	10	15	60	30,000	0	No Cracks	Passed
83	15	20	60	30,000	0	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area of .03637 square inches.

(2) Stress calculated at twice nominal diameter area, .09817 square inches.

TABLE XX

MECHANICAL PROPERTIES

Part No. VS 2502-8-48 - Material - A-286 (200 ksi)
Part No. Nut VN 466-B-080 – Material A-286 (200 ksi)
Size - 1/2-20

1. Tensile - Base Material Properties (As Received)
.357 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	251,800	208,100	11.4	36.0
2	-423	238,100	213,100	13.6	37.3
3	-423	250,800	202,200	15.7	37.5
4	70	195,900	154,700	14.2	39.7
5	70	195,900	155,700	14.2	38.1
6	70	196,900	155,700	15.0	38.5
7	1200	142,500	137,500	11.4	37.3
8	1200	141,500	137,500	11.4	58.8
9	1200	145,000	142,500	9.3	56.7

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)	Yield Load, pounds	Yield Stress, psi
10	-423	43,500	272,000	32,250	202,000
11	-423	42,800	268,000	33,000	206,000
12	-423	43,500	272,000	32,750	205,000
13	70	35,000	218,800	24,000	150,000
14	70	34,700	217,000	24,000	150,000
15	70	34,700	217,000	24,300	151,900
16	1200	26,500	166,000	23,000	143,500
17	1200	26,600	166,500	23,750	148,000
18	1200	26,300	164,500	23,250	145,500

(1) Stress calculated at tensile stress area of .1599 square inches.

TABLE XX (continued)

Part No. VS 2502-8-48
VN 466-B-080

1. Tensile (continued) -

Base Material Properties (As cycled)
.357 Specimens
Cycled 12 Times
Seated at 104,000 PSI

70° to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, 1.4 in. %	Red. of Area, %
19	70	199,100	152,400	14.0	34.5
20	70	199,100	163,000	14.0	39.6
21	70	194,700	161,100	14.0	40.1

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	34,150	213,500	24,400	152,500
23	70	34,100	213,200	24,6000	153,800
24	70	34,450	215,400	24,700	154,400
		As Relaxed - 50 hours			
Preload A					
25	70	33,100	207,000	23,200	145,100
26	70	33,000	206,400	22,300	139,500
27	70	33,900	212,000	24,200	151,300
Preload B					
28	70	33,100	207,000	23,200	145,100
29	70	34,500	215,800	24,000	150,100
30	70	34,500	215,800	23,500	147,000

TABLE XX (continued)

Part No. VS 2502-8-48
VN 466-B-080

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
31 (a)	-423	32,000	145,000
32 (a)	-423	32,300	146,500
33 (a)	-423	32,000	145,000
34	70	46,700	118,900
35	70	46,300	118,400
36	70	46,200	117,600
37	1200	32,500	82,700
38	1200	32,500	82,700
39	1200	32,800	83,500

(a) .375 inch diameter

"As Cycled"

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 1200°F to 70°F

40	70	43,900	111,800
41	70	43,800	111,500
42	70	43,900	111,800

As Relaxed - 50 Hours

Preload A

43	70	45,000	114,600
44	70	44,200	112,600
45	70	45,200	115,100

Preload B

46	70	41,400	105,400
47	70	45,200	115,000
48	70	44,600	113,600

TABLE XX (continued)

Part No. VS 2502-8-48
VN 466-B-080

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
49	1200	12,800	80,000	137.8	N.F.
50	1200	12,800	80,000	115.5	N.F.
51	1200	12,800	80,000	103.1	T
52	1200	15,990	100,000	16.1	T
53	1200	15,990	100,000	54.1	T
54	1200	15,990	100,000	38.2	T
55	1200	19,200	120,000	2.3	T
56	1200	19,200	120,000	.3	T
57	1200	19,200	120,000	1.8	T

4. Stress Relaxation @1200°F -

Preload A - Initial Stress - 89,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
58	10	6,490	40,600
59	10	7,900	49,400
60	10	Fastener damaged in disassembly	
61	50	5,836	36,500
62	50	4,700	29,400
63	50	5,292	33,100

Preload B - Initial Stress - 51,800 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
64	10	5,996	37,500
65	10	6,396	40,000
66	10	6,396	40,000
67	50	5,788	36,200
68	50	4,000	29,400
69	50	4,988	31,200

TABLE XX (continued)

Part No. VS 2502-8-48
Nut VN 466-B-080

5. Nut Reuse and Galling Tendency (continued)

After Soak at 70° F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
70	65	108,000	1560	1200	50
71	70	108,000	1200	720	60
72	65	108,000	1440	1200	65
73	70	180,000	1320	1080	50
74	70	180,000	1440	1200	45
2nd Application					
70	40	108,000	1200	1080	50
71	50	108,000	2200	960	50
72	50	108,000	1440	1200	50
73	50	108,000	1320	1080	40
74	50	108,000	1440	1320	45
3rd Application					
70	60	108,000	1440	1200	55
71	50	108,000	1200	840	55
72	45	108,000	1320	1200	50
73	50	108,000	1440	1080	45
74	50	108,000	1440	1320	45
4th Application					
70	65	108,000	1440	1200	50
71	55	108,000	1260	840	55
72	50	108,000	1440	1080	55
73	60	108,000	1320	1080	55
74	50	108,000	1440	1200	45
5th Application					
70	55	108,000	1560	1260	45
71	55	108,000	1260	960	60
72	50	108,000	1140	1080	55
73	55	108,000	1200	1080	60
74	45	108,000	1440	1140	45

TABLE XX (continued)

Part No. VS 2502-8-48
Nut VN 466-B-080

5. Nut Reuse and Galling Tendency (continued) -

After Soak at 1200°F

Test No.	Maximum Installation inch-pounds	Seated Stress, psi(1)	Torque to Induce Stress, inch-pounds	Torque After Soak Breakaway	Removal
1st Application					
75	70	108,000	1880	4400	85
76	70	108,000	1440	4200	90
77	75	108,000	1560	3800	110
78	65	108,000	1320	4000	90
79	60	108,000	1560	4600	90
2nd Application					
75	70	108,000	3600	4200	80
76	80	108,000	3400	4400	60
77	80	108,000	3000	4000	100
78	70	108,000	3200	4400	60
79	70	108,000	3200	5000	90
3rd Application					
75	70	108,000	3400	3400	60
76	80	108,000	3600	4200	70
77	90	108,000	3000	4200	80
78	70	108,000	3400	4000	70
79	60	108,000	3400	4400	90
4th Application					
75	70	108,000	3600	4200	70
76	75	108,000	3600	4600	60
77	80	108,000	3800	4400	80
78	70	108,000	3400	4600	70
79	75	108,000	3400	4800	75
5th Application					
75	70	180,000	3400	3800	60
76	70	180,000	3600	4400	70
77	90	180,000	3800	4200	75
78	55	180,000	3400	4400	70
79	60	180,000	3800	4600	70

TABLE XX (continued)

Part No. VS 2502-8-48
Nut - VN 466-B-080

6. Torque vs. Induced Load @ Room Temperature -

Torque inch-pounds	Test No. 80 Load, pounds	Test No. 81 Load, pounds	Test No. 82 Load, pounds
400	3,000	2,750	3,000
800	7,500	6,500	7,000
1200	12,250	11,000	12,000
1600	18,500	19,000	18,500
2000	22,000	23,000	22,500
2400	26,250	28,000	27,000
2800	28,750	30,000	28,500

Note: Height of nut and short thread length of bolt prevented complete engagement of nut threads.

7. Vibration - ALMA #10 -

Test No.	Maximum Installation, 1st	5th	Seating Torque, inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
83	90	40	300	30,000	0°	No Cracks	Passed
84	75	60	300	30,000	0°	No Cracks	Passed
85	50	40	300	30,000	0°	No Cracks	Passed
86	60	30	300	30,000	45°	No Cracks	Passed
87	80	40	300	30,000	0°	No Cracks	Passed

(1) Stress calculated at Tensile Stress Area of .1599 square inches.

(2) Stress calculated at twice nominal diameter area, .3927 square inches.

APPENDIX II

TEST RESULTS

SHEAR BOLTS - PHASE II

TABLE XXI

SUMMARY OF RESULTS

EWSB 926 & EWSN 926 - MATERIAL H-11 (260 KSI)

Material Properties -

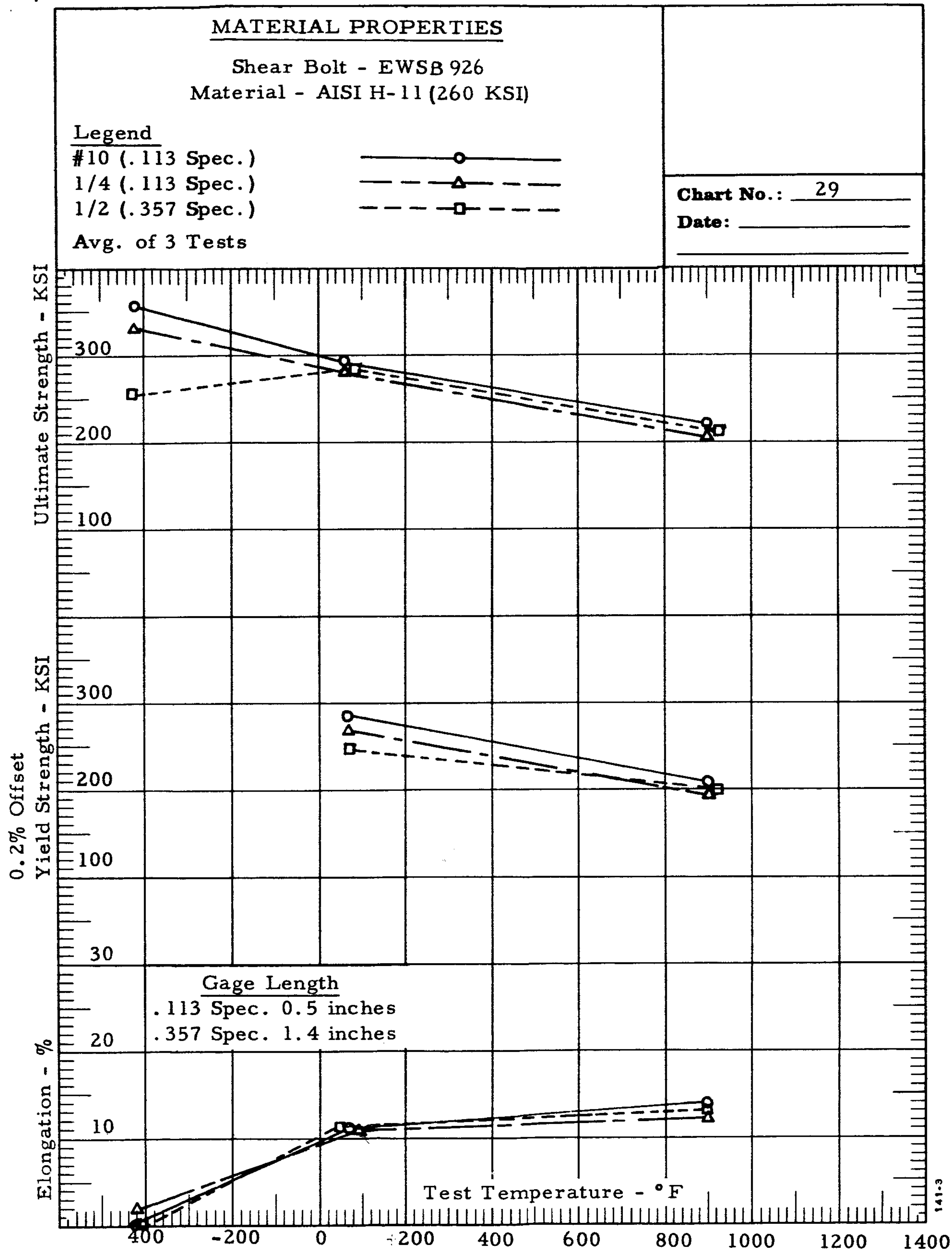
Test Temp.	U. T. S., - KSI #10	U. T. S., - KSI 1/4	U. T. S., - KSI 1/2	0.2% Offset Yield, - KSI #10	0.2% Offset Yield, - KSI 1/4	0.2% Offset Yield, - KSI 1/2	Elongation, - % #10	Elongation, - % 1/4	Elongation, - % 1/2
-423°F	360.2	284.9	241.2	N. Y.	N. Y.	N. Y.	*	2.0	-
	318.3	331.6	201.4	N. Y.	N. Y.	N. Y.	*	-	-
	373.6	364.6	264.3	N. Y.	N. Y.	N. Y.	*	-	-
70°F	295.0	278.9	283.1	284.0	260.0	239.6	10.0	12.0	10.7
	294.6	282.5	281.5	281.9	267.0	239.6	14.0	10.0	11.4
	294.7	278.0	286.1	281.5	266.3	244.6	10.0	10.0	10.0
900°F	222.5	211.2	212.5	211.0	196.4	195.9	14.0	12.0	13.5
	221.0	213.1	211.0	210.0	196.8	196.0	14.0	12.0	13.5
	209.6	210.9	218.0	196.2	195.3	205.0	14.0	12.0	11.4

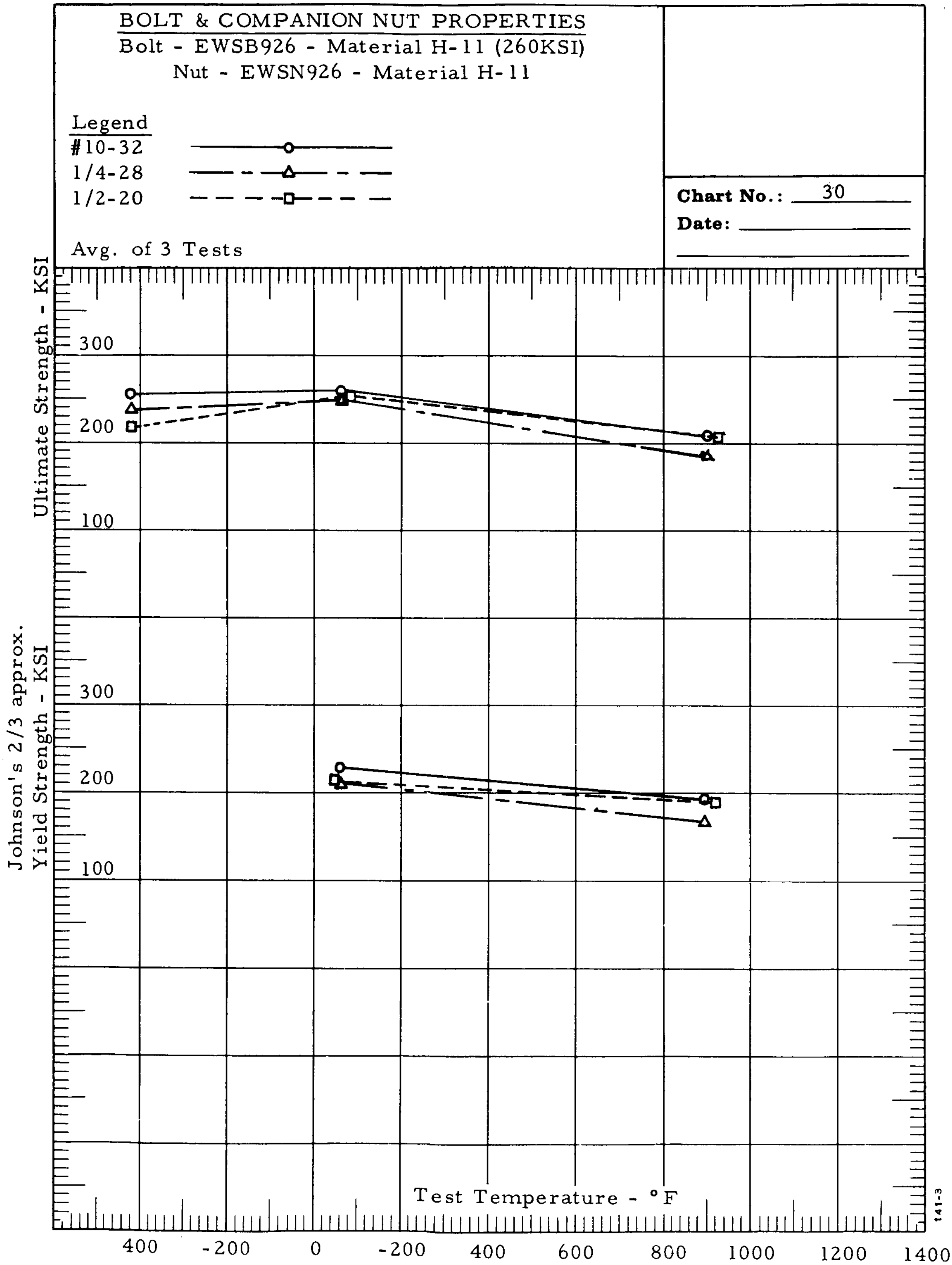
Test Temp.	Reduction of Area - % #10	Reduction of Area - % 1/4	Reduction of Area - % 1/2	Shear Strength - KSI #10	Shear Strength - KSI 1/4	Shear Strength - KSI 1/2
-423°F	*	-	-	212.6	197.6	Test
	*	-	-	215.1	163.0	Not
	*	3.6	-	194.0	190.4	Conducted
70°F	40.8	52.3	40.4	186.9	180.3	172.9
	42.7	44.7	43.0	186.0	178.3	174.9
	39.0	50.0	38.7	186.2	180.3	175.7
900°F	57.2	50.2	52.3	130.0	138.5	124.0
	54.8	52.3	54.4	121.7	138.5	124.0
	55.1	55.5	51.8	130.0	130.4	127.8

Bolt & Nut Properties -

Test Temp.	U. T. S., - KSI #10	U. T. S., - KSI 1/4	U. T. S., - KSI 1/2	Johnson's 2/3 Approx. Yield, - KSI #10	Johnson's 2/3 Approx. Yield, - KSI 1/4	Johnson's 2/3 Approx. Yield, - KSI 1/2
-423°F	278.5 (H)	255.0 (N. S.)	215.6 (H)	N. Y.	N. Y.	N. Y.
	218.9 (H)	222.8 (H)	225.0 (H)	N. Y.	N. Y.	N. Y.
	265.3 (H)	222.8 (H)	206.5 (H)	N. Y.	N. Y.	N. Y.
70°F	265.2 (N. S.)	240.0	250.5 (N. S.)	212.2	207.9	213.8
	265.2 (N. S.)	257.4	252.3 (N. S.)	256.4	210.3	207.4
	237.6 (N. S.)	245.0	249.4 (N. S.)	215.5	202.9	210.3
900°F	208.6 (N. S.)	183.1	228.9 (N. S.)	194.5	173.2	201.0
	214.4 (N. S.)	185.6	193.8 (N. S.)	205.5	163.9	180.7
	188.9 (N. S.)	180.6	217.1 (N. S.)	179.0	157.7	189.4

N. Y. - No Yield
H - Head Failure
N. S. - Nut Stripped
* - Specimen Fractured Outside Gage
(1) Stress calculated at pitch diameter area


MATERIAL PROPERTIES
Shear Bolt - EWSB 926
Material - AISI H-11 (260 KSI)
Legend
#10 (.113 Spec.)
1/4 (.113 Spec.)
1/2 (.357 Spec.)
Avg. of 3 Tests
Chart No.: 29
Date:
Ultimate Strength - KSI
300
200
100
0.2% Offset
Yield Strength - KSI
300
200
100
30
Gage Length
.113 Spec. 0.5 inches
.357 Spec. 1.4 inches
20
10
Elongation - %
Test Temperature - °F
400
-200
0
200
400
600
800
1000
1200
1400
141-3



BOLT & COMPANION NUT PROPERTIES
Bolt - EWSB926 - Material H-11 (260KSI)
Nut - EWSN926 - Material H-11
Legend
#10-32
1/4-28
1/2-20
Avg. of 3 Tests
Chart No.: 30
Date:
Ultimate Strength - KSI
300
200
100
Johnson's 2/3 approx.
Yield Strength - KSI
300
200
100
Test Temperature - °F
400
-200
0
-200
400
600
800
1000
1200
1400
141-3

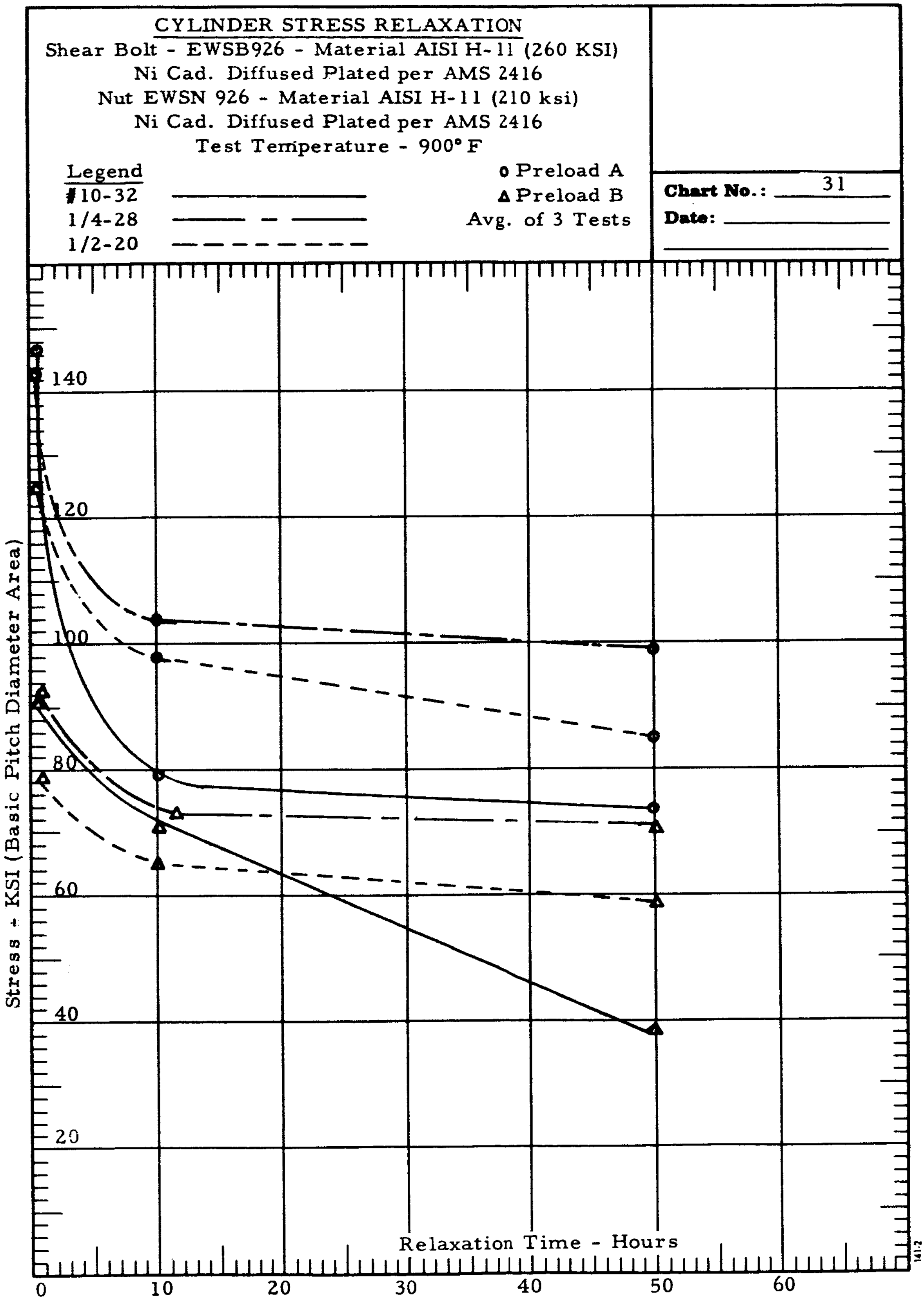

CYLINDER STRESS RELAXATION
Shear Bolt - EWSB926 - Material AISI H-11 (260 KSI)
Ni Cad. Diffused Plated per AMS 2416
Nut EWSN 926 - Material AISI H-11 (210 ksi)
Ni Cad. Diffused Plated per AMS 2416
Test Temperature - 900° F
Legend
#10-32
1/4-28
1/2-20
o Preload A
Δ Preload B
Avg. of 3 Tests
Chart No.: 31
Date:
140
120
100
80
60
40
20
0
10
20
30
40
50
60
Stress ÷ KSI (Basic Pitch Diameter Area)
Relaxation Time - Hours

TABLE XXII

MECHANICAL PROPERTIES

Part No. EWSB 926-3-36 - Material - AISI H-11 (260 ksi)
Part No. Nut EWSN 926-3 - Material AMS 6304 (210 ksi)
Size #10-32

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
1	-423	360,200	No Yield	Specimen Fractured	
2	-423	318,300	No Yield	Outside Gage	
3	-423	373,600	No Yield		
4	70	295,000	284,000	10.0	40.8
5	70	294,600	281,900	14.0	42.7
6	70	294,700	281,500	10.0	39.0
7	900	222,500	211,000	14.0	57.2
8	900	221,000	210,000	14.0	54.8
9	900	209,600	196,200	14.0	55.1

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	6,300 (H)	278,500	No Yield	
11	-423	4,950 (H)	218,900	No Yield	
12	-423	6,000 (H)	265,300	No Yield	
13	70	6,000 (N.S.)	265,200	4,800	212,200
14	70	6,000 (N.S.)	265,200	5,800	256,400
15	70	5,375 (N.S.)	237,600	4,875	215,500
16	900	4,720 (N.S.)	208,600	4,400	194,500
17	900	4,850 (N.S.)	214,400	4,650	205,500
18	900	4,275 (N.S.)	188,900	4,050	179,000

(1) Stress calculated at basic pitch dia. area of .02262 square inches.
H - Head Failure
N.S. - Nut Stripped

TABLE XXII (continued)

Part No. EWSB 926-3-36
EWSN 926-3

1. Tensile (continued) -

Base Material Properties (As cycled)
.113 Specimens
Cycled 12 times
Seated at 85,000 psi

70° to -423°F to 70°F

Test No.	Test Temp. °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
19	70	295,500	286,900	10.0	43.0
20	70	294,400	263,900	10.0	44.0
21	70	296,800	268,800	8.0	41.0

70°F to 900°F to 70°F

Test No.	Test Temp. °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
22	70	285,700	271,000	10.0	44.5
23	70	290,500	267,300	10.0	44.5
24	70	Specimen was damaged			

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
25	70	6,000 (N.S.)	265,300	4,950	218,800
26	70	5,680 (N.S.)	251,100	5,300	234,300
27	70	5,620 (N.S.)	248,500	4,720	208,700

70°F to 900°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
28	70	5,720 (N.S.)	252,800	5,200	229,800
29	70	5,600 (N.S.)	247,500	5,200	229,800
30	70	6,030	266,500	5,150	227,600

N. S. - Nut Stripped

TABLE XXII (continued)

Part No. EWSB 926-3-36
EWSN 926-3

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
31	70	6,700	296,100	5,300	234,300
32	70	5,540 (N.S.)	244,900	5,300	234,300
33	70	5,750	254,100	5,150	227,600

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
34	70	5,130 (N.S.)	226,700	4,400	194,500
35	70	5,720	252,800	4,670	206,400
36	70	5,460 (N.S.)	241,300	4,580	202,400

N.S. Nut Stripped

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
37	-423	12,000	212,600
38	-423	12,200	215,100
39	-423	11,000	194,000
40	70	9,450	166,600
41	70	9,450	166,600
42	70	9,460	166,800
43	900	7,375	130,000
44	900	6,900	121,700
45	900	7,375	130,000

(2) Stress calculated at twice nominal dia., .05671 square inches.

TABLE XXII (continued)

Part No. EWSB 926-3-36
EWSN 926-3

2. Double Shear - (continued)

"As Cycled"

70°F to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
46	70	9,400	165,800
47	70	9,460	166,800
48	70	9,430	166,300

70°F to 900°F to 70°

49	70	9,400	165,800
50	70	9,400	165,800
51	70	9,480	167,200

As Relaxed - 50 Hours

Preload A

52	70	9,100	160,500
53	70	9,230	162,800
54	70	9,170	161,700

Preload B

55	70	9,200	162,000
56	70	9,400	165,500
57	70	9,100	160,500

TABLE XXII (continued)

Part No. EWSB 926-3-36
EWSN 926-3

3. Stress Rupture -

Stress rupture tests at 900° F were not conducted. Fastener assembly is not considered rupture sensitive as evidenced by 1/4 inch results which show the stress required for 100 hour life was 95 percent of the 900° F yield strength.

4. Stress Relaxation @ 900° F -

Preload A - Initial Stress - 146,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
58	10	2,000	88,500
59	10	1,775	78,500
60	10	1,626	71,900
61	50	1,526	67,500
62	50	1,750	77,400
63	50		

Preload B - Initial Stress - 90,800 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
64	10	1,526	67,500
65	10	1,651	73,000
66	10	1,628	72,000
67	50	1,025	45,300
68	50	798	35,300
69	50	748	33,100

TABLE XXII (continued)

Part No. EWSB 926-3-36
Nut - EWSN 926-3

5. Torque vs. Induced Load @ Room Temperature -

Torque, inch-pounds	Test No. 70 Load, pounds	Test No. 71 Load, pounds	Test No. 72 Load, pounds
30	950	950	800
40	1500	1350	1400
50	2000	1850	1850
60	2550	2300	2450
70	3050	2850	3050
80	3650	3400	3600
90	4150	4000	4200
100	4800	4550	4650
110	5200	4900	5100
120	--	5300	5400

(1) Stress calculated at Basic P. D. of .02262 square inches.

(2) Stress calculated at twice nominal diameter area, .05671 square inches.

TABLE XXIII

MECHANICAL PROPERTIES

Part No. EWSB 926-4-34 - Material - AISI H-11 (260 ksi)
Part No. Nut EWSN 926-4 - Material AMS 6304 (210 ksi)
Size - 1/4-28

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area %
1	-423	284,900	No Yield	2.0	-
2	-423	331,600	No Yield	-	-
3	-423	364,600	359,400	-	3.6
4	70	278,900	260,000	12.0	52.3
5	70	282,500	267,000	10.0	44.7
6	70	278,000	266,300	10.0	50.0
7	900	211,200	196,400	12.0	50.2
8	900	213,100	196,800	12.0	52.3
9	900	210,900	195,300	12.0	55.5

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	10,300 (N.S.)	255,000	No Yield	
11	-423	9,000 (H)	222,800	No Yield	
12	-423	9,000 (H)	222,800	No Yield	
13	70	9,700 (N.S.)	240,000	8,400	207,900
14	70	10,400 (N.S.)	257,400	8,500	210,300
15	70	9,900 (N.S.)	245,000	8,200	202,900
16	900	7,400 (N.S.)	183,100	7,000	173,200
17	900	7,500 (N.S.)	185,600	6,625	163,900
18	900	7,300 (N.S.)	180,600	6,375	157,700

(1) Stress calculated at basic pitch dia. area of .0404 square inches.
N.S. - Nut Stripped
H - Head Failure

TABLE XXIII (continued)

Part No. EWSB 926-4-34
EWSN 926-4

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	70	9,700 (N. S.)	240,100	6,700	165,800
20	70	10,000 (N. S.)	247,500	9,900	245,000
21	70	10,000 (N. S.)	247,500	9,250	228,900

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	10,500 (N. S.)	259,900	9,350	231,400
23	70	10,600 (N. S.)	262,400	9,350	231,400
24	70	10,400 (N. S.)	257,400	8,750	216,600

N. S. Nut Stripped

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
25	-423	19,400	197,600
26	-423	16,000	163,000
27	-423	18,700	190,400
28	70	17,700	180,300
29	70	17,500	178,300
30	70	17,700	180,300
31	900	13,600	138,500
32	900	13,600	138,500
33	900	12,800	130,400

(2) Stress calculated at twice nominal dia. area, .09817 square inches.

TABLE XXIII (continued)

Part No. EWSB 926-4-34
EWSN 926-4

2. Double Shear - (continued) -

"As Relaxed - 50 Hours"

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
34	70	17,200	175,200
35	70	17,300	176,200
36	70	17,400	177,200

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
37	70	17,500	178,300
38	70	17,350	176,700
39	70	17,400	177,200

TABLE XXIII (continued)

Part No. EWSB 926-4-34
EWSN 926-4

3. Stress Rupture -

Test No.	Test Temp, °F	Load pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
40	900	6,868	170,000	1.1	N.S.
41	900	6,464	160,000	1.5	N.S.
42	900	6,060	150,000	70.4	N.S.
43	900	6,060	150,000	153.5	N.S.
44	900	6,060	150,000	51.5	N.S.

Testing discontinued as fastener assembly is not considered rupture sensitive. The stress required for 100 hour life is 95 percent of the 900°F yield strength.

4. Stress Relaxation @ 900°F -

Preload A - Initial Stress - 142,300 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
45	10	4,150	102,700
46	10	4,070	100,700
47	10	4,340	107,400
48	50	4,150	102,700
49	50	4,070	100,700
50	50	3,800	94,000

Preload B - Initial Stress - 92,800 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
51	10	2,950	73,000
52	10	3,100	76,700
53	10	2,800	69,300
54	50	2,900	71,700
55	50	2,950	73,000
56	50	2,850	70,500

TABLE XXIII (continued)

Part No. EWSB 926-4-34
Nut - EWSN 926-4

5. Torque vs. Induced Load @ Room Temperature -

Torque inch- pounds	Test No. 57 Load, pounds	Test No. 58 Load, pounds	Test No. 59 Load, pounds
50	1100	850	1000
100	2250	1850	2200
150	3600	2800	3350
200	4650	3850	4650
250	5850	5050	5700
300	6850	6300	6700
350	7900	7250	7600
400	9000	7950	8350
450	9500	8850	9050
500	9500	--	--

(1) Stress calculated at Basic P. D. of .0404 square inches.

(2) Stress calculated at twice nominal diameter area, .09817 square inches.

TABLE XXIV

MECHANICAL PROPERTIES

Part No. EWSB 926-8-50 - Material - AISI H-11 (260 ksi)
Part No. Nut EWSN 926-8 - Material AMS 6304 (210 ksi)
Size 1/2-20

1. Tensile - Base Material Properties (As Received)
.357 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area %
1	-423	241,200	No Yield	Spec. fractured outside gage	
2	-423	201,400	No Yield	-	-
3	-423	264,300	No Yield	-	2.2
4	70	283,100	239,600	10.7	40.4
5	70	281,500	239,600	11.4	43.0
6	70	286,100	244,600	10.0	38.7
7	900	212,500	195,900	13.5	52.3
8	900	211,000	196,000	13.5	54.4
9	900	218,000	205,000	11.4	51.8

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	37,000 (H)	215,600	No Yield	
11	-423	38,600 (H)	225,000	No Yield	
12	-423	35,500 (H)	206,500	No Yield	
13	70	43,000 (N.S.)	250,500	36,700	213,800
14	70	43,300 (N.S.)	252,300	35,600	207,400
15	70	42,800 (N.S.)	249,400	36,100	210,300
16	900	39,250 (N.S.)	228,900	34,500	201,000
17	900	33,250 (N.S.)	193,800	31,000	180,700
18	900	37,250 (N.S.)	217,100	32,500	109,400

(1) Stress calculated at basic pitch dia. area of .1716 square inches.
H - Head Failure
N.S. - Nut Stripped

TABLE XXIV (continued)

Part No. EWSB 926-8-50
EWSN 926-8

1. Tensile (continued) -

Base Material Properties (As cycled)
.357 Specimens
Cycled 12 times
Seated at 85,000 psi

70° to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 900°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, 1.4 in. %	Red. of Area, %
19	70	282,300	236,500	10.0	38.3
20	70	278,000	231,000	14.0	39.3
21	70	274,700	230,200	11.4	42.5

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F - Cycling Test Not Conducted.

70°F to 900°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	48,500 (N.S.)	282,600	37,400	217,900
23	70	48,700 (N.S.)	283,700	38,400	223,700
24	70	49,000	285,500	38,000	221,400
Bolt & Nut Properties As Relaxed - 50 Hours					
Preload A					
25	70	47,700 (N.S.)	278,000	38,000	221,400
26	70	48,200	280,900	39,600	230,800
27	70	48,100	280,300	38,200	222,600
Preload B					
28	70	47,700	278,000	37,000	215,600
29	70	48,500	282,600	36,700	213,900
30	70	48,600	283,200	37,600	219,100

TABLE XXIV (continued)

Part No. EWSB 926-8-50
EWSN 926-8

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
	-423	Tests not conducted. Shear fixtures being redesigned.	
31	70	67,900	172,900
32	70	68,200	174,900
33	70	69,000	175,700
34	900	49,000	124,000
35	900	49,000	124,000
36	900	50,300	127,800

"As Cycled"

70°F to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 900°F to 70°F

37	70	70,500	179,500
38	70	68,800	177,700
39	70	69,600	177,200

As Relaxed - 50 Hours

Preload A

40	70	65,100	165,800
41	70	65,000	165,500
42	70	63,800	162,400

Preload B

43	70	66,300	168,800
44	70	66,300	168,800
45	70	65,300	166,300

(2) Stress calculated at twice nominal dia. area, .3927 square inches.

TABLE XXIV (continued)

Part No. EWSB 926-8-50
EWSN 926-8

3. Stress Rupture

Stress rupture tests at 900° F were not conducted. Fastener assembly is not considered rupture sensitive as evidenced by 1/4 inch results which show the stress required for 100 hour life was 95 percent of the 900° F yield strength.

4. Stress Relaxation @ 900° F

Preload A - Initial Stress - 125,500 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
46	10	17,330	101,000
47	10	16,818	98,000
48	10	16,010	93,300
49	50	14,688	85,600
50	50	14,277	83,200

Preload B - Initial Stress - 78,700 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
51	10	11,754	68,500
52	10	10,810	63,000
53	10	10,810	63,000
54	50	10,000	58,300
55	50	9,798	57,100
56	50	10,210	59,500

TABLE XXIV (continued)

Part No. EWSB 926-8-50
Nut - EWSN 926-8

5. Torque vs. Induced Load @ Room Temperature -

Torque, inch-pounds	Test No. 57 Load, pounds	Test No. 58 Load, pounds	Test No. 59 Load, pounds
400	6,500	7,000	6,500
800	16,000	13,000	13,000
1200	23,000	21,500	22,000
1600	30,500	27,500	28,000
2000	35,000	33,000	33,500
2400	39,000	35,000	39,000
2800	40,000	37,000	---

(1) Stress calculated at Basic P.D. of .1716 square inches.

(2) Stress calculated at twice nominal diameter area, .3927 square inches.

TABLE XXV

SUMMARY OF RESULTS

NAS 673 & FN12 - MATERIAL Ti 6Al-4V (160 KSI)

Material Properties -

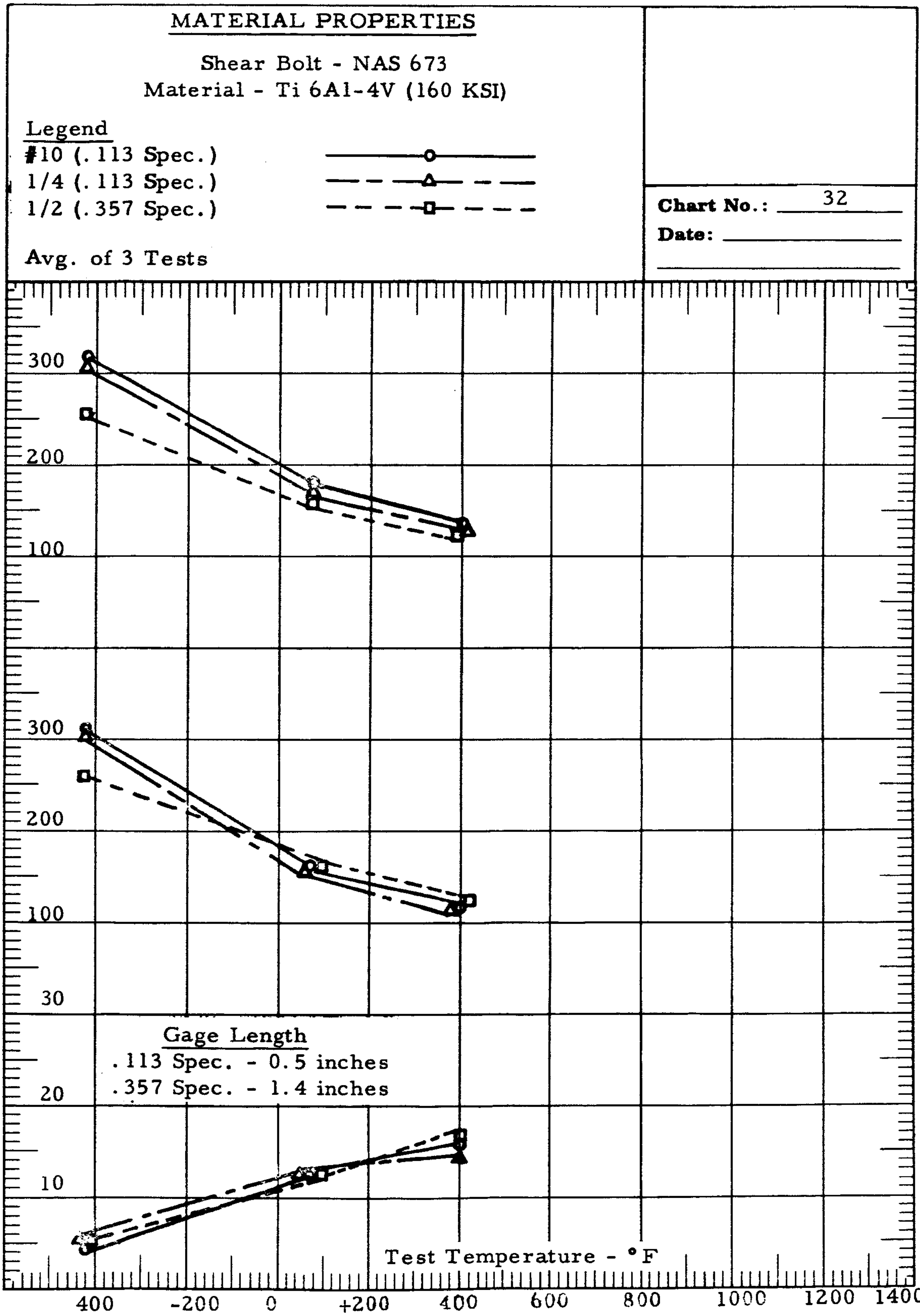
Test Temp.	U. T. S. - KSI #10	U. T. S. - KSI 1/4	U. T. S. - KSI 1/2	0.2% Offset Yield - KSI #10	0.2% Offset Yield - KSI 1/4	0.2% Offset Yield - KSI 1/2	Elongation - % #10	Elongation - % 1/4	Elongation - % 1/2
-423° F	325.0	312.5	246.0	315.1	307.3	239.0	4.0	6.0	6.3
	321.4	314.6	271.4	313.8	312.5	266.3	6.0	6.0	5.7
	319.4	310.4	274.4	316.3	310.4	264.2	4.0	6.0	5.7
70° F	176.0	176.8	171.1	160.2	159.1	161.3	12.0	12.0	13.5
	181.1	173.1	164.8	166.3	158.6	162.7	12.0	12.0	13.5
	176.0	172.9	165.6	162.2	156.2	161.5	14.0	12.0	14.2
400° F	138.0	135.2	128.6	120.0	116.3	123.6	16.0	14.0	16.4
	135.0	136.7	135.6	117.5	117.3	123.6	16.0	14.0	15.7
	-	135.4	131.0	-	118.7	121.0	-	12.0	18.5

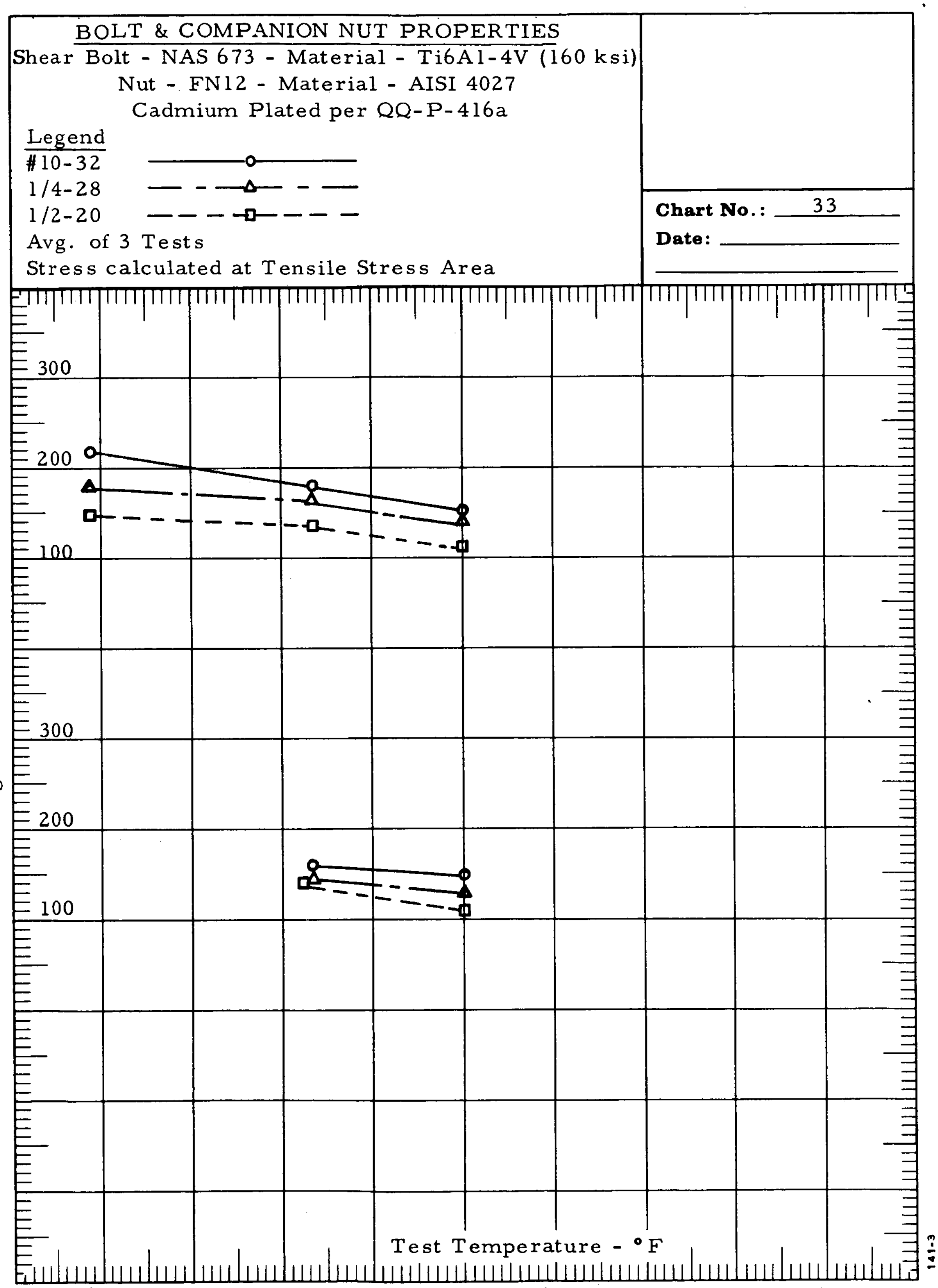
Test Temp.	Reduction of Area - % #10	Reduction of Area - % 1/4	Reduction of Area - % 1/2	Shear Strength-KSI #10	Shear Strength-KSI 1/4	Shear Strength-KSI 1/2
-423° F	25.2	32.8	34.1	151.6	132.4	Test
	29.6	28.3	28.5	155.2	137.5	Not
	10.4	26.7	26.8	144.6	142.3	Conducted
70° F	53.8	48.7	45.4	111.4	108.0	115.9
	53.8	47.5	52.0	113.2	112.0	114.1
	55.3	48.4	51.7	113.4	112.0	110.8
400° F	59.5	57.3	57.0	83.8	76.4	85.3
	57.2	58.3	55.3	79.8	78.4	90.6
	-	56.7	58.0	79.4	75.4	92.9

Bolt & Nut Properties -

Test Temp.	U. T. S. - KSI (1) #10	U. T. S. - KSI (1) 1/4	U. T. S. - KSI (1) 1/2	Johnson's 2/3 Approx. Yield - KSI #10	Johnson's 2/3 Approx. Yield - KSI 1/4	Johnson's 2/3 Approx. Yield - KSI 1/2
-423° F	230.1 (N.S.)	170.5	157.5 (N.C.)	N.Y.	N.Y.	N.Y.
	205.0	176.0 (N.S.)	164.5 (N.C.)	N.Y.	N.Y.	N.Y.
	222.6 (N.S.)	189.7	139.5 (N.C.)	N.Y.	N.Y.	N.Y.
70° F	186.0	167.7 (N.S.)	142.5 (N.S.)	167.5	140.2	140.2
	181.5	173.2	140.7 (N.S.)	161.0	153.9	140.0
	180.0	164.4	139.4 (N.S.)	159.5	148.4	138.8
400° F	158.1	148.4 (N.S.)	101.6 (N.S.)	145.1	137.2	100.0
	158.8	148.4 (N.S.)	110.0 (N.S.)	147.6	134.7	109.4
	164.0	145.7 (N.S.)	121.3 (N.S.)	143.0	130.6	118.1

N.S. Nut Stripped
N.C. Nut Cracked
(1) Stress calculated at tensile stress area


MATERIAL PROPERTIES
Shear Bolt - NAS 673
Material - Ti 6Al-4V (160 KSI)
Legend
#10 (.113 Spec.)
1/4 (.113 Spec.)
1/2 (.357 Spec.)
Avg. of 3 Tests
Chart No.: 32
Date:
Ultimate Strength - KSI
0.2% Offset Yield Strength - KSI
Elongation - %
300
200
100
300
200
100
30
20
10
Gage Length
.113 Spec. - 0.5 inches
.357 Spec. - 1.4 inches
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3


BOLT & COMPANION NUT PROPERTIES
Shear Bolt - NAS 673 - Material - Ti6Al-4V (160 ksi)
Nut - FN12 - Material - AISI 4027
Cadmium Plated per QQ-P-416a
Legend
#10-32
1/4-28
1/2-20
Avg. of 3 Tests
Stress calculated at Tensile Stress Area
Chart No.: 33
Date:
Ultimate Strength- KSI
300
200
100
Johnson's 2/3 Approx.
Yield Strength - KSI
300
200
100
Test Temperature - °F
400
-200
0
+200
400
600
800
1000
1200
1400
141-3

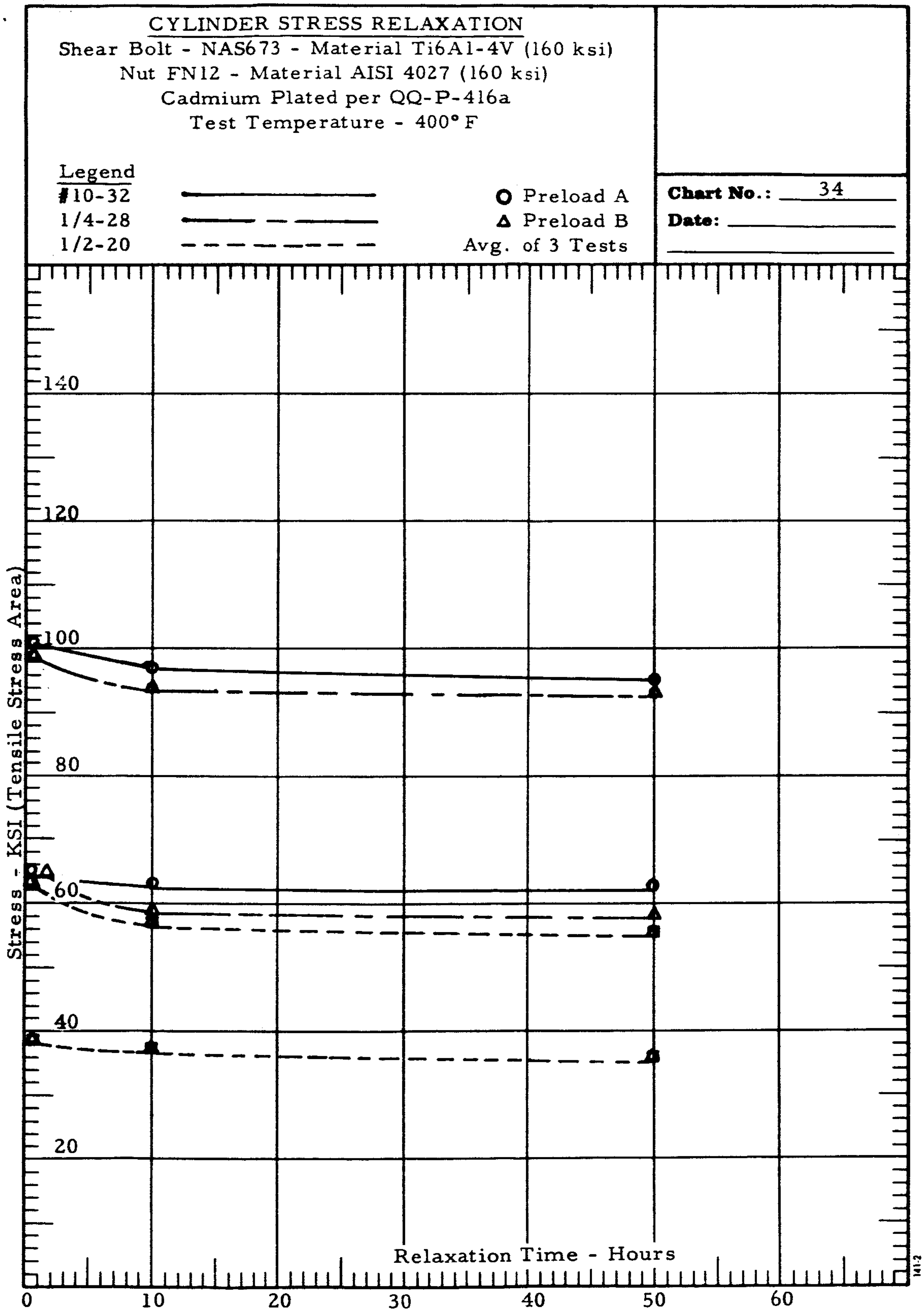

CYLINDER STRESS RELAXATION
Shear Bolt - NAS673 - Material Ti6Al-4V (160 ksi)
Nut FN12 - Material AISI 4027 (160 ksi)
Cadmium Plated per QQ-P-416a
Test Temperature - 400° F
Legend
#10-32
1/4-28
1/2-20
O Preload A
Δ Preload B
Avg. of 3 Tests
Chart No.: 34
Date:
Stress - KSI (Tensile Stress Area)
140
120
100
80
60
40
20
Relaxation Time - Hours
0
10
20
30
40
50
60
141-2

TABLE XXVI

MECHANICAL PROPERTIES

Part No. NAS 673V-36 - Material - Ti 6Al-4V (160 ksi)
Part No. Nut FN12-02 Material AISI 4027 (160 ksi)
Size - #10-32x2.588

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	325,000	315,100	4.0	25.2
2	-423	321,400	313,800	6.0	29.6
3	-423	319,400	316,300	4.0	10.4
4	70	176,000	160,200	12.0	53.8
5	70	181,100	166,300	12.0	53.8
6	70	176,000	162,200	14.0	55.3
7	400	138,000	120,000	16.0	59.5
8	400	135,000	117,500	16.0	57.2
9	400	-	-	-	-

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	4,600 (N.S.)	230,100	No Yield	
11	-423	4,100	205,100	No Yield	
12	-423	4,450 (N.S.)	222,600	No Yield	
13	70	3,720	186,000	3,350	167,500
14	70	3,630	181,500	3,220	161,000
15	70	3,600	180,000	3,190	159,500
16	400	3,160	158,000	2,900	145,100
17	400	3,175	158,800	2,950	147,600
18	400	3,280	164,000	2,860	143,000

(1) Stress calculated at tensile stress area of .01999 square inches.
N. S. - Nut Stripped

TABLE XXVI (continued)

Part No. NAS 673V-36
FN 12-02

1. Tensile (continued) -

Base Material Properties (As cycled)
.113 Specimens
Cycled 12 Times
Seated at 77,000 psi

70° to -423°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
19	70	175,300	159,800	12.0	49.0
20	70	170,100	153,600	12.0	50.5
21	70	178,900	162,100	12.0	50.0

70°F to 400°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
22	70	172,100	147,300	14.0	49.8
23	70	163,400	152,600	14.0	51.3
24	70	174,400	158,800	14.0	48.8

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F

Test No.	Test Temp. °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
25	70	3,660	183,100	3,350	167,600
26	70	3,810	190,100	3,400	170,100
27	70	3,740	187,100	3,300	165,100

70°F to 400°F to 70°F

Test No.	Test Temp. °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
28 (a)	70	3,650	182,500	3,150	157,500
29 (a)	70	3,700	185,000	3,150	157,500
30 (a)	70	3,740	187,100	Not Tested	---
31 (b)	70	3,550	177,600	3,050	152,600
32 (b)	70	3,570	178,600	3,220	161,000

(a) Fast Cycle
(b) Slow Cycle

TABLE XXVI (continued)

Part No. NAS 673V-36
FN 12-02

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
33	70	3,750	187,500	3,520	176,000
34	70	3,825	191,300	3,400	170,000
35	70	3,775	188,800	3,500	175,000

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
36	70	3,620	181,000	3,280	164,000
37	70	3,680	184,000	3,350	167,500
38	70	3,670	183,500	3,340	167,000

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
39	-423	8,600	151,600
40	-423	8,800	155,200
41	-423	8,200	144,600
42	70	5,500	97,800
43	70	5,750	101,400
44	70	5,660	99,800
45	400	4,750	83,800
46	400	4,525	79,800
47	400	4,500	79,400

(2) Stress calculated at twice nominal dia. area, .05671 square inches.

TABLE XXVI (continued)

Part No. NAS 673V-36
FN 12-02

2. Double Shear - (continued)

"As Cycled"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
70°F to -423°F to 70°F			
48	70	5,720	100,800
49	70	5,900	104,000
50	70	5,810	102,500
70°F to 400°F to 70°F			
51	70	5,690	100,300
52	70	5,830	102,800
53	70	5,710	100,700
As Relaxed - 50 Hours			
Preload A			
54	70	5,800	102,300
55	70	5,800	102,300
56	70	5,900	104,000
Preload B			
57	70	5,270	92,900
58	70	5,370	94,700
59	70	5,310	93,600

TABLE XXVI (continued)

Part No. NAS 673V-36
FN 12-02

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
60	400	3,200	160,100	---	Failed loading
61	400	3,040	152,100	100	No failure
62	400	3,040	152,100	---	Failed loading
63	400	3,040	152,100	118	No failure
64	400	3,040	152,100	100	No failure

Testing discontinued as fastener assembly is not considered rupture sensitive. The stress required for 100 hour life is above the 400° F yield strength.

4. Stress Relaxation @ 400° F

Preload A - Initial Stress - 101,000 psi

Test No.	Hours Run	Residual Stress pounds	psi(1)
65	10	1,919	96,000
66	10	1,939	97,000
67	10	Specimen damaged in disassembly.	
68	50	1,900	95,500
69	50	1,900	95,000
70	50	1,900	95,000

Preload B - Initial Stress - 63,750 psi

Test No.	Hours Run	Residual Stress pounds	psi(1)
71	10	1,259	63,000
72	10	1,259	63,000
73	10	1,259	63,000
74	50	1,259	63,000
75	50	1,259	63,000
76	50	1,259	63,000

TABLE XXVI (continued)

Part No. NAS 673V-36
Nut - FN 12-02

5. Torque vs. Induced Load @ Room Temperature -

Torque, inch-pounds	Test No. 77 Load, pounds	Test No. 78 Load, pounds	Test No. 79 Load, pounds
20	850	1000	750
30	1400	1650	1200
40	1900	2350	1500
50	2400	2850	2100
60	2950	3300 (B.B.)	3150
70	3500 (B.B.)	--	3350 (B.B.)

B.B. - Bolt Broke

(1) Stress calculated at tensile stress area of .01999 square inches.

(2) Stress calculated at twice nominal diameter area, .05671 square inches.

TABLE XXVII

MECHANICAL PROPERTIES

Part No. NAS 674V-38 Material Ti 6Al-4V (160 ksi)
Part No. Nut FN12-048
Size - 1/4-28x2.800

1. Tensile - Base Material Properties (As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	312,500	307,300	6.0	32.8
2	-423	314,600	312,500	6.0	28.3
3	-423	310,400	310,400	6.0	26.7
4	70	176,800	159,100	12.0	48.7
5	70	173,100	158,600	12.0	47.5
6	70	179,900	156,200	12.0	48.4
7	400	135,200	116,300	14.0	57.3
8	400	136,700	117,300	14.0	58.3
9	400	135,400	118,700	12.0	56.7

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	6,200	170,500	No Yield	
11	-423	6,400 (N.S.)	176,000	No Yield	
12	-423	6,900	189,700	No Yield	
13	70	6,100 (N.S.)	167,700	5,100	140,200
14	70	6,300	173,200	5,600	153,900
15	70	5,980	164,400	5,400	148,400
16	400	5,400 (N.S.)	148,400	4,990	137,200
17	400	5,400 (N.S.)	148,400	4,900	134,700
18	400	5,300	145,700	4,750	130,600

(1) Stress calculated at tensile stress area of .03637 square inches.
N.S. - Nut Stripped

TABLE XXVII (continued)

Part No. NAS 674V-38
FN 12-048

1. Tensile (continued) -

Bolt & Nut Properties
As Relaxed - 50 Hours

Preload A

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	70	6,160	169,300	5,810	159,700
20	70	6,250	171,800	5,990	164,600
21	70	6,080	167,100	5,700	156,700

Preload B

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	6,080	167,200	5,700	156,700
23	70	6,080	167,200	5,600	154,000
24	70	6,220	171,000	5,875	161,500

TABLE XXVII (continued)

Part No. NAS 674V-38
FN 12-048

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress psi(2)
25	-423	13,000	132,400
26	-423	13,500	137,500
27	-423	14,000	142,300
28	70	10,600	108,000
29	70	11,000	112,000
30	70	11,000	112,000
31	400	7,500	76,400
32	400	7,700	78,400
33	400	7,400	75,400

As Relaxed - 50 Hours

Preload A

34	70	10,800	110,000
35	70	10,700	109,000
36	70	10,800	110,000

Preload B

37	70	10,600	108,000
38	70	10,500	107,000
39	70	10,500	107,000

(2) Stress calculated at twice nominal dia area, .09817 square inches.

TABLE XXVII (continued)

Part No. NAS 674V-38
FN 12-048

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time Hrs.	Location of Failure
40	400	5,640	155,000	---	Failed loading
41	400	5,410	150,000	113.2	No failure
42	400	5,460	150,000	---	Failed loading
43	400	5,460	150,000	---	Failed loading
44	400	5,270	145,000	102.0	No failure
45	400	5,270	145,000	141.1	No failure

Testing discontinued as fastener assembly is not considered rupture sensitive. The stress required for 100 hour life was above the 400°F yield strength.

4. Stress Relaxation @400°F

Preload A - Initial Stress - 100,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
46	10	3,400	93,500
47	10	3,426	94,200
48	10	3,255	89,500
49	50	3,309	91,000
50	50	3,447	94,800
51	50	3,353	92,200

Preload B - Initial Stress - 65,000 psi

52	10	2,150	59,100
53	10	2,200	60,400
54		Specimen damaged in disassembly	
55	50	2,200	60,400
56	50	2,180	59,900
57	50	2,120	58,200

TABLE XXVII (continued)

Part No. NAS 674V-38
Nut - FN 12-048

5. Torque vs. Induced Load @ Room Temperature -

Torque, inch-pounds	Test No. 58 Load, pounds	Test No. 59 Load, pounds	Test No. 60 Load, pounds
50	500	1150	1450
75	1500	2000	2000
100	2450	2650	3000
125	3300	3500	4000
150	3950	4750	4750
175	5100	5500	5300
200	5600	5700	5600
225	B.B.	B.B.	B.B.

B.B. - Bolt broke

(1) Stress calculated at tensile stress area of .03637 square inches.

(2) Stress calculated at twice nominal diameter area, .09817 square inches.

TABLE XXVIII

MECHANICAL PROPERTIES

Part No. NAS 678V-46 - Material - Ti 6Al-4V (160 ksi)
Part No. Nut FN12-080 - Material AISI 4027 (160 ksi)
Size - 1/2-20

1. Tensile - Base Material Properties (As Received)
.357 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
1	-423	246,000	239,000	6.3	34.1
2	-423	271,400	266,300	5.7	28.5
3	-423	274,400	264,200	5.7	26.8
4	70	171,100	161,300	13.5	45.4
5	70	164,800	162,700	13.5	52.0
6	70	165,600	161,500	14.2	51.7
7	400	128,600	123,600	16.4	57.0
8	400	135,600	123,600	15.7	55.3
9	400	131,000	121,000	18.5	58.0

Bolt & Nut Properties (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
10	-423	24,200 (N.C.)	157,500	No Yield	-
11	-423	26,300 (N.C.)	164,500	No Yield	-
12	-423	22,300 (N.C.)	139,500	No Yield	-
13	70	22,800 (N.S.)	142,500	22,500	140,700
14	70	22,500 (N.S.)	140,700	22,400	140,000
15	70	22,300 (N.S.)	139,400	22,200	138,800
16	400	16,250 (N.S.)	101,600	16,000	100,000
17	400	17,600 (N.S.)	110,000	17,500	109,400
18	400	19,400 (N.S.)	121,300	18,900	118,100

N.C. - Nut Cracked
N.S. - Nut Stripped
(1) Stress calculated at tensile stress area of .1599 square inches.

TABLE XXVIII (continued)

Part No. NAS 678V-46
FN 12-080

1. Tensile (continued) -

Base Material Properties (As cycled)
.357 Specimens
Cycled 12 Times
Seated at 77,000 psi

70° to -423°F to 70°F - Cycling Tests Not Conducted.

70°F to 400°F to 70°F

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, 1.4 in. %	Red. of Area %
19	70	167,800	163,300	15.0	53.8
20	70	169,800	169,300	15.7	52.0
21	70	167,800	166,800	15.7	52.0

Bolt & Nut Properties (As Cycled)

70°F to -423°F to 70°F - Cycling Tests Not Conducted

70°F to 400°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
22	70	21,500 (N.S.)	134,500	No Yield	
23	70	23,800 (N.S.)	148,800	No Yield	
24	70	22,500	140,700	No Yield	
		As Relaxed - 50 hours			
Preload A					
25	70	23,750 (N.S.)	148,500	No Yield	
26	70	22,000 (N.S.)	137,500	No Yield	
27	70	23,400 (N.S.)	146,300	No Yield	
Preload B					
28	70	23,500 (N.S.)	146,900	No Yield	
29	70	24,000 (N.S.)	150,000	No Yield	
30	70	23,250 (N.S.)	145,400	No Yield	

N. S. - Nut Stripped

TABLE XXVIII (continued)

Part No. NAS 678V-46
FN 12-080

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
	-423	Tests not conducted.	Shear fixtures being redesigned.
31	70	45,500	115,900
32	70	44,800	114,100
33	70	43,500	110,800
34	400	33,500	85,300
35	400	35,600	90,600
36	400	36,500	92,900

"As Cycled"

70°F to -423°F to 70°F - Cycling Tests not conducted.

70°F to 400°F to 70°F

37	70	41,900	106,700
38	70	40,300	102,600
39	70	41,900	106,700

As Relaxed - 50 Hours

Preload A

40	70	41,500	105,700
41	70	40,800	103,900
42	70	40,700	103,600

Preload B

43	70	41,000	104,400
44	70	42,100	107,200
45	70	40,900	104,200

(2) Stress calculated at twice nominal dia. area, .3927 square inches.

TABLE XXVIII (continued)

Part No. NAS 678V-46
FN 12-080

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
46	400	19,200	120,000	---	Failed loading
47	400	18,400	115,000	100.6	No failure
48	400	18,400	115,000	---	Failed loading
49	400	18,400	115,000	160.0	No failure
50	400	18,400	115,000	100,8	No failure
51	400	17,600	110,000	100.0	No failure

Testing discontinued as fastener assembly was not considered rupture sensitive. The stress required for 100 hour life is above the 400° F yield strength.

4. Stress Relaxation @ 400° F

Preload A - Initial Stress - 63,200 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
52	10	9,498	59,400
53	10	9,498	59,400
54	10	9,498	59,400
55	50	9,194	57,500
56	50	9,146	57,200
57	50	9,194	57,400

Preload B - Initial Stress - 38,300 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
58	10	5,996	37,500
59	10	5,996	37,500
60	10	5,996	37,500
61	50	5,788	36,200
62	50	5,884	36,800
63	50	5,644	35,300

TABLE XXVIII (continued)

Part No. NAS 678V-46
Nut - FN 12-080

6. Torque vs. Induced Load @ Room Temperature -

Torque, inch-pounds	Test No. 64 Load, pounds	Test No. 65 Load, pounds	Test No. 66 Load, pounds
300	2,000		2,000
400	3,250	2,500	3,000
500	5,000	4,000	4,060
600	7,500	5,500	6,000
700	10,000	8,000	7,250
800	11,500	9,500	8,500
900	13,500	11,500	10,000
1,000	17,000	13,500	13,000
1,100	18,000	14,500	14,500
1,200	Nut Hex Reamed	16,000	16,000
1,300	----	18,000	18,000

(1) Stress calculated at tensile stress area of .1599 square inches.

(2) Stress calculated at twice nominal diameter area, .3927 square inches.

APPENDIX III

TEST RESULTS

POINT DRIVE FASTENERS AND JO BOLTS - PHASE II

TABLE XXIX

SUMMARY OF RESULTS

Point Drive Bolt & Twist-Off Nut
HL 10V 70W
Material - Ti 6Al-4V & Al 2024

Test Temp.	Ult. Strength (ksi) (1)			Shear Strength (ksi) (2)		
	#10	1/4	3/8	#10	1/4	3/8
-423°F	139.0 (NS)	136.9 (NS)	64.9 (H)	141.1	137.5	Test
	153.1 (NS)	130.6 (NS)	127.5 (H)	175.1	137.5	Not
	150.1 (NS)	132.0 (NS)	134.4 (H)	127.0	120.2	Conducted
70°F	99.0 (NS)	97.2 (NS)	91.7 (NS)	109.3	108.0	104.6
	99.8 (NS)	93.5 (NS)	89.4 (NS)	116.0	109.0	114.1
	101.0 (NS)	93.5 (NS)	98.5 (NS)	121.7	112.0	111.4
250°F	98.0 (NS)	92.6 (NS)	91.1 (NS)	84.2	89.6	96.0
	92.0 (NS)	86.1 (NS)	94.4 (NS)	89.5	93.7	91.0
	93.0 (NS)	85.9 (NS)	97.1 (NS)	92.6	95.6	96.0

(1) Stress calculated at tensile stress area.
(2) Stress calculated at twice nominal diameter area.
(NS) Nut Stripped
(H) Head Failure

TABLE XXX

MECHANICAL PROPERTIES

Part No. HL10V 70W-6-40 Bolt Material - Ti6Al-4V - Nut Material - 2024 Al
Size - #10-32

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
1	-423	--	--	2,780 (N.S.)	139,100
2	-423	--	--	3,060 (N.S.)	153,100
3	-423	--	--	3,000 (N.S.)	150,100
4	70	1,700	85,043	1,980 (N.S.)	99,050
5	70	1,680	84,042	1,995 (N.S.)	99,800
6	70	1,575	78,789	2,020 (N.S.)	101,051
7	250	-	-	1,960 (N.S.)	98,050
8	250	-	-	1,850 (N.S.)	92,546
9	250	-	-	1,860 (N.S.)	93,047

"As Cycled"

70° to -423°F to 70°F - Cycling tests not conducted.

70°F to 250°F to 70°F

10	70	1,500	75,038	2,060 (N.S.)	103,052
11	70	1,200	60,030	2,055 (N.S.)	102,801
12	70	1,650	82,541	1,950 (N.S.)	97,549

(1) Stress calculated at tensile stress area of .01999 square inches.
(N.S.) - Nut Stripped

TABLE XXX (continued)

Part No. HL 10V 70W-6-40

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
13	-423	8,000	141,100
14	-423	9,930	175,100
15	-423	7,200	127,000
16	70	5,950	104,920
17	70	5,920	104,391
18	70	5,670	99,982
19	250	4,775	84,200
20	250	5,075	89,500
21	250	5,250	92,600

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

22	70	5,470	96,456
23	70	6,040	106,507
24	70	6,200	109,328

3. Vibration - ALMA #10 -

Test No.	Installation Torque inch-pounds	Breakoff Torque inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp	Remarks
25	12	28	30,000	0	No cracks	Passed
26	14	38	30,000	10	No cracks	Passed
27	15	30	30,000	0	No cracks	Passed
28	17	33	30,000	0	No cracks	Passed
29	15	30	30,000	0	No cracks	Passed

(2) Stress calculated at twice nominal diameter area, 05671 square inches.

TABLE XXXI

MECHANICAL PROPERTIES

Part No. HL 10V 70W-8-42 Bolt Material - Ti-6Al-4V - Nut Material 2024 Al
Size 1/4-28

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
1	-423			4,750 (N.S.)	130,600
2	-423			4,800 (N.S.)	132,000
3	-423			3,535 (N.S.)	97,200
4	70	1,750	48,117	3,535 (N.S.)	97,195
5	70	1,400	38,493	3,400 (N.S.)	93,484
6	70	1,900	52,240	3,400 (N.S.)	93,484
7	250			3,370 (N.S.)	92,659
8	250			3,130 (N.S.)	86,060
9	250			3,125 (N.S.)	85,923

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
10	-423	13,500	137,500
11	-423	13,500	137,500
12	-423	11,800	120,200
13	70	10,600	107,976
14	70	10,700	108,995
15	70	11,000	112,051
16	250	8,800	89,600
17	250	9,200	93,700
18	250	7,400	95,600

(1) Stress calculated at tensile stress area of .03637 square inches.
(2) Stress calculated at twice nominal diameter area, .09817 square inches.

TABLE XXXI (continued)

Part No. HL 10V-70W-8-42

3. Vibration - ALMA #10 -

Test No.	Installation Torque inch-pounds	Breakoff Torque inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp	Remarks
19	28	70	30,000	30	No cracks	Passed
20	18	75	30,000	10	No cracks	Passed
21	20	68	30,000	0	No cracks	Passed
22	30	70	30,000	0	No cracks	Passed
23	20	58	30,000	20	No cracks	Passed

TABLE XXXII

MECHANICAL PROPERTIES

Part No. HL 10V-70W-12-48 Bolt Material - Ti6Al-4V Nut Material 2024 Al
Size 3/8-24

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
1	-423			5,700 (H. F.)	64,900
2	-423			11,200 (H. F.)	127,500
3	-423			11,800 (H. F.)	134,400
4	70	5,800	66,100	8,050 (N. S.)	91,700
5	70	5,600	63,800	7,850 (N. S.)	89,400
6	70	6,500	74,000	8,650 (N. S.)	98,500
7	250			8,000 (N. S.)	91,100
8	250			8,250 (N. S.)	94,000
9	250			8,525 (N. S.)	97,100

"As Cycled"

70°F to -423°F to 70°F - Cycling tests not conducted.

70°F to 250°F to 70°F

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
10	70	5,500	62,600	7,500 (N. S.)	85,400
11	70	1,500	17,100	8,000 (N. S.)	91,100
12	70	2,500	28,500	8,300 (N. S.)	94,500

(1) Stress calculated at tensile stress area of .0878 square inches.
(H. F.) Head Failure
(N. S.) Nut Stripped

TABLE XXXII (continued)

Part No. HL 10V 70W-12-48

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
	-423	Tests not conducted, shear fixtures being redesigned	
13	70	23,100	104,600
14	70	25,200	114,100
15	70	24,600	111,400
16	250	21,100	96,000
17	250	20,000	91,000
18	250	21,000	96,000

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

19	70	23,000	104,200
20	70	25,100	113,700
21	70	25,100	113,700

3. Vibration - ALMA #10 -

Test No.	Installation Torque inch-pounds	Breakoff Torque inch-pounds	No. of Cycles	Degrees Movement	10x Mag. Visual Insp.	Remarks
22	85	200	30,000	0	No cracks	Passed
23	80	200	30,000	0	"	"
24	80	200	30,000	0	"	"
25	90	200	30,000	0	"	"
26	80	200	30,000	0	"	"

(2) Stress calculated at twice nominal diameter area, .2208 square inches.

TABLE XXXIII

SUMMARY OF RESULTS

Point Drive Bolt & Twist-Off Nut
HL 1870W
Material - AISI 8740 & Al 2024

Test Temp.	Ult. Strength (ksi) (1)			Shear Strength (ksi) (2)		
	#10	1/4	3/8	#10	1/4	3/8
-423°F	143.6 (NS)	139.7 (NS)	80.1 (H)	155.2	152.8	Not Tested
	139.1 (NS)	135.3 (NS)	103.1 (H)	151.6	158.9	
	149.1 (NS)	140.8 (NS)	103.6 (H)	153.4	163.0	
70°F	98.5 (NS)	90.5 (NS)	99.1 (NS)	111.0	111.0	99.6
	95.0 (NS)	91.8 (NS)	100.2 (NS)	112.9	112.0	99.6
	96.0 (NS)	94.0 (NS)	100.2 (NS)	109.3	111.0	100.1
250°F	93.0 (NS)	79.2 (NS)	100.2 (NS)	91.2	100.8	96.5
	94.5 (NS)	80.3 (NS)	96.8 (NS)	93.9	102.9	97.7
	91.0 (NS)	91.3 (NS)	96.8 (NS)	92.1	100.8	97.2

(1) Stress calculated at tensile stress area.
(2) Stress calculated at twice nominal diameter area.

TABLE XXXIV

MECHANICAL PROPERTIES

Part No. HL 1870W-6-40 Bolt Material AI SI 8740 - Nut Material 2024 Al
Size #10-32

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load pounds	Ult. Stress, psi
1	-423			2,870 (N.S.)	143,600
2	-423			2,780 (N.S.)	139,100
3	-423			2,980 (N.S.)	149,100
4	70	1,720	86,043	1,970 (N.S.)	98,549
5	70	1,500	75,038	1,900 (N.S.)	95,048
6	70	1,700	85,043	1,920 (N.S.)	96,048
7	250			1,860 (N.S.)	93,047
8	250			1,890 (N.S.)	94,547
9	250			1,820 (N.S.)	91,046

"As Cycled"

70°F to -423°F to 70°F - Cycling tests not conducted.

70°F to 250°F to 70°F

10	70	800	40,020	1,975 (N.S.)	98,799
11	70	1,075	53,777	1,975 (N.S.)	98,799
12	70	1,400	70,035	2,040 (N.S.)	102,051

(1) Stress calculated at tensile stress area of .01999 square inches.
(N.S.) - Nut Stripped

TABLE XXXIV (continued)

Part No. HL 1870W-6-40

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
13	-423	8,800	155,200
14	-423	8,600	151,600
15	-423	8,700	153,400
16	70	5,500	96,985
17	70	5,500	96,985
18	70	5,500	96,985
19	250	5,175	91,200
20	250	5,325	93,900
21	250	5,225	92,100

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

22	70	5,420	95,574
23	70	5,460	96,279
24	70	5,440	95,927

3. Vibration - ALMA #10 -

Test No.	Installation Torque inch-pounds	Breakoff Torque inch-pounds	No. of Cycles	Degrees Movement	10x Mag. Visual Insp.	Remarks
25	6	28	30,000	60	No cracks	Passed
26	7	30	30,000	60	No cracks	Passed
27	7	28	30,000	90	No cracks	Passed
28	6	29	30,000	90	No cracks	Passed
29	10	29	30,000	30	No cracks	Passed

(2) Stress calculated at twice nominal diameter area, .05671 square inches.

TABLE XXXV

MECHANICAL PROPERTIES

Part No. HL 1870W-8-42 - Bolt Material AISI 8740 - Nut Material 2024 Al
Size - 1/4-28

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult, Stress, psi
1	-423			5,080 (N.S.)	139,700
2	-423			4,920 (N.S.)	135,300
3	-423			5,120 (N.S.)	140,800
4	70	2,090	57,465	3,290 (N.S.)	90,459
5	70	2,350	64,614	3,340 (N.S.)	91,834
6	70	2,425	66,676	3,250 (N.S.)	89,359
7	250			2,880 (N.S.)	79,186
8	250			2,920 (N.S.)	80,286
9	250			3,320 (N.S.)	91,284

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
10	-423	15,000	152,800
11	-423	15,600	158,900
12	-423	16,000	163,000
13	70	10,900	111,032
14	70	11,000	112,051
15	70	10,900	111,032
16	250	9,900	100,800
17	250	10,100	102,900
18	250	9,900	100,800

(1) Stress calculated at tensile stress area of .03637 square inches.
(2) Stress calculated at twice nominal diameter area, .09817 square inches.
(N.S.) Nut Stripped

TABLE XXXV (continued)

Part No. HL 1870 W-8-42

3. Vibration - ALMA #10 -

Test No.	Installation Torque inch-pounds	Breakoff Torque inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
19	12	63	18,000	Complete motion failure		
20	10	75	18,000	"	"	"
21	9	65	18,000	"	"	"
22	9	65	18,000	"	"	"
23	11	68	18,000	"	"	"

TABLE XXXVI

MECHANICAL PROPERTIES

Part No. HL 1870W-12-48 Bolt Material AISI 8740 - Nut Material 2024 A1
Size 3/8-24

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
1	-423			7,030 (H. F.)	80,100
2	-423			9,050 (H. F.)	103,100
3	-423			9,100 (H. F.)	103,600
4	70	3,100	35,300	8,700 (N. S.)	99,078
5	70	3,100	35,300	8,800 (N. S.)	100,216
6	70	2,600	29,610	8,800 (N. S.)	100,216
7	250			8,800 (N. S.)	100,216
8	250			8,500 (N. S.)	96,800
9	250			8,500 (N. S.)	96,800

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
10	70	2,000	22,777	8,950 (N. S.)	101,925
11	70	1,900	21,638	8,900 (N. S.)	101,355
12	70	2,100	23,915	8,975 (N. S.)	102,209

(1) Stress calculated at tensile stress area of .0878 square inches.
(H. F.) Head Failure
(N. S.) Nut Stripped

TABLE XXXVI (continued)

Part No. HL 1870W-12-48

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
	-423	Test not conducted, shear fixtures being redesigned	
13	70	22,000	99,638
14	70	22,000	99,638
15	70	22,100	100,091
16	250	21,200	96,500
17	250	21,500	97,700
18	250	21,400	97,200

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
19	70	21,700	98,279
20	70	21,600	97,826
21	70	21,700	98,279

3. Vibration - ALMA #10 -

Test No.	Installation Torque inch-pounds	Breakoff Torque inch-pounds	No. of Cycles	Degrees Movement	10x Mag. Visual Insp.	Remarks
22	33	195	30,000	90	No cracks	Passed
23	30	200	30,000	90	No cracks	Passed
24	33	200	30,000	90	No cracks	Passed
25	37	190	30,000	30	No cracks	Passed
26	35	190	30,000	45	No cracks	Passed

(2) Stress calculated at twice nominal diameter area, .2208 square inches.

TABLE XXXVII

SUMMARY OF RESULTS

Point Drive Bolt & Twist-Off Nut
HL 4078
Material - A-286

Test Temp.	Ult. Strength (ksi) (1) #10	Ult. Strength (ksi) (1) 1/4	Shear Strength (ksi) (2) #10	Shear Strength (ksi) (2) 1/4
-423°F	217.6 (H)	181.5 (H)	161.5	160.9
	200.1 (H)	194.7 (H)	164.0	149.7
	220.1 (H)	193.6 (H)	160.5	152.8
70°F	151.6 (H)	148.0 (H)	109.3	118.9
	149.1 (T)	149.8 (T)	109.9	118.9
	147.6 (T)	141.6 (H)	109.2	118.9
1200°F	80.0 (H)	111.5 (H)	63.9	75.4
	95.5 (H)	110.0 (H)	63.0	76.9
	95.0 (H)	112.0 (H)	66.1	75.4

(1) Stress calculated at tensile stress area.
(2) Stress calculated at twice nominal diameter area.
(H) Head Failure
(T) Thread Failure

TABLE XXXVIII

MECHANICAL PROPERTIES

Part No. HL 4078-6-40 Material A-286 (140 ksi)
Size 3/16 x 2 1/2" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
1	-423			4,350 (H)	217,600
2	-423			4,000 (H)	200,100
3	-423			4,400 (T)	220,100
4	70	1,400	70,000	3,030 (H)	151,600
5	70	1,700	85,000	2,980 (T)	149,100
6	70	1,500	75,000	2,950 (T)	147,600
7	1200			1,600 (H)	80,000
8	1200			1,910 (H)	95,500
9	1200			1,900 (H)	95,000

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
10	70	1,000	50,000	3,030 (H)	151,600
11	70	750	37,500	2,900 (H)	145,100
12	70	1,000	50,000	2,980 (H)	149,100

"As Relaxed - 50 hours"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
13	70	700	35,000	3,300 (H)	165,100
14	70	775	38,100	2,900 (H)	145,100
15	70	750	37,500	3,100 (H)	155,100

(1) Stress calculated at tensile stress area of .01999 square inches.
(H) Head Failure
(T) Thread Failure

TABLE XXXVIII (continued)

Part No. HL 4078-6-40

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
16	-423	9,160	161,500
17	-423	9,300	164,000
18	-423	9,100	160,500
19	70	5,520	97,300
20	70	5,500	97,000
21	70	5,500	97,000
22	1200	3,625	63,900
23	1200	3,575	63,000
24	1200	3,750	66,100

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

25	70	5,700	100,500
26	70	5,740	101,200
27	70	5,720	100,900

"As Relaxed - 50 Hours"

28	70	5,780	101,900
29	70	5,840	103,000
30	70	5,800	102,300

(2) Stress calculated at twice nominal diameter area, .05671 square inches.

TABLE XXXVIII (continued)

Part No. HL 4078-6-40

3. Stress Relaxation @ 1200°F -

Initial Preload - 76,600 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress PSI (1)
31	10	750	37,500
32	10	925	51,000
33	10	825	41,500
34	50	700	35,000
35	50	775	38,800
36	50	750	37,500

4. Vibration - ALMA #10 -

Test No.	Installation Torque inch-pounds	Breakoff Torque inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
37	10	45	30,000	90	No cracks	Passed
38	8	48	30,000	80	"	"
39	8	40	30,000	0	"	"
40	8	45	30,000	20	"	"
41	10	45	30,000	0	"	"

(1) Stress calculated at tensile stress area of .01999 square inches.

TABLE XXXIX

MECHANICAL PROPERTIES

Part No. HL 4078-8-42 - Material A-286
Size 1/4-28

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
1	-423			6,600 (H)	181,500
2	-423			7,080 (H)	194,700
3	-423			7,020 (H)	193,000
4	70	3,000	82,500	5,400 (H)	148,474
5	70	4,000	110,000	5,450 (T)	149,849
6	70	3,950	108,600	5,150 (H)	141,600
7	1200			4,050 (H)	111,500
8	1200			4,000 (H)	110,000
9	1200			4,075 (H)	112,200

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
10	70	2,750	75,600	5,000 (H)	137,500
11	70	2,500	68,700	4,700 (H)	129,200
12	70	2,850	78,400	4,700 (H)	129,200

"As Relaxed - 50 Hours"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
13	70	1,700	46,700	5,100 (H)	140,200
14	70	1,500	41,200	5,400 (H)	148,500
15	70	1,500	41,200	4,850 (H)	133,400

(1) Stress calculated at tensile stress area of .03637 square inches.
(H) Head Failure
(T) Thread Failure

TABLE XXXIX (continued)

Part No. HL 4078-8-42

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
16	-423	15,800	160,900
17	-423	14,700	149,700
18	-423	15,000	152,800
19	70	11,200	118,934
20	70	11,200	118,934
21	70	11,200	118,934
22	1200	7,400	75,400
23	1200	7,550	76,900
24	1200	7,400	75,400

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
25	70	10,620	108,200
26	70	10,800	110,000
27	70	10,720	109,200

"As Relaxed - 50 Hours"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
28	70	12,000	122,200
29	70	11,600	118,200
30	70	11,700	119,200

(2) Stress calculated at twice nominal diameter area, .09817 square inches.

TABLE XXXIX (continued)

Part No. HL 4078-8-42

3. Stress Relaxation @ 1200°F -

Initial Preload - 100,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress PSI (1)
31	10	1,150	31,600
32	10	1,300	35,700
33	10	1,650	45,500
34	50	1,700	46,700
35	50	1,500	41,200
36	50	1,500	41,200

4. Vibration - ALMA #10 -

Test No.	Installation Torque inch-pounds	Breakoff Torque inch-pounds	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
37	30	120	30,000	0	No cracks	Passed
38	28	120	30,000	0	No cracks	Passed
39	18	120	30,000	0	No cracks	Passed
40	22	120	30,000	20	No cracks	Passed
41	16	120	30,000	0	No cracks	Passed

(1) Stress calculated at tensile stress area of .03637 square inches.

TABLE XL

SUMMARY OF RESULTS

#10 Jo Bolts
Materials - AISI 4130 - PP 200
A-286 PP 200A

Test Temp.	Ult. Strength (ksi) (1)		Shear Strength (ksi) (2)	
	4130	A-286	4130	A-286
-423°F	109.1	157.1	73.2	138.5
	122.6	147.7	89.1	141.7
	135.1	165.1	89.0	158.8
70°F	104.5	95.0	83.6	83.6
	93.8	96.0	84.7	83.1
	114.3	91.3	84.8	83.2
Max.	450°F	1200°F	450°F	1200°F
	76.8	80.0	79.6	57.7
	74.5	65.0	70.4	60.5
	76.0	65.0	75.6	62.1

(1) Stress calculated at tensile stress area of .01999 square inches.
(2) Stress calculated at twice nominal diameter area, .06283 square inches.

TABLE XLI

MECHANICAL PROPERTIES

Part No. PP 200-16 Bolt & Nut Material AISI 4130 - Sleeve Material 303 S/S
Size #10 x 1.0"

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
1	-423			2,180	109,100 (T)
2	-423			2,450	122,600 (T)
3	-423			2,700	135,100 (T)
4	70	1,000	50,025	2,090	104,552 (T)
5	70	950	47,524	1,875	93,797 (N.S.)
6	70	700	35,018	2,285	114,307 (T)
7	450			1,535	76,800
8	450			1,490	74,500
9	450			1,520	76,000

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 450°F to 70°F

10	70	550	27,500	2,325	116,300 (T)
11	70	900	45,000	1,970	98,500 (N.S.)
12	70	975	48,800	2,120	106,000 (T)

(1) Stress calculated at tensile stress area of .01999 square inches.
(T) Thread Failure
(N.S.) Nut Stripped

TABLE XLI (continued)

Part No. PP 200-16

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
13	-423	4,600	73,200
14	-423	5,600	89,100
15	-423	5,600	89,100
16	70	5,250	83,600
17	70	5,320	84,700
18	70	5,330	84,800
19	450	5,000	79,600
20	450	4,425	70,400
21	450	4,750	75,600

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 450°F to 70°F

22	70	5,680	90,400
23	70	5,250	83,700
24	70	5,330	84,000

(2) Stress calculated at twice nominal diameter area, .06283 square inches.

TABLE XLII

MECHANICAL PROPERTIES

Part No. PP 200A-16 Bolt & Nut Material A-286, Rc 30
Sleeve Material A-286 (Solution Treated)
Size #10

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
1	-423			3,140	157,100 (T)
2	-423			2,950	147,600 (T)
3	-423			3,300	165,100 (T)
4	70	800	40,000	1,900	95,000 (N.S.)
5	70	700	35,000	1,920	96,000 (T)
6	70	725	36,300	1,825	91,300 (N.S.)
7	1200			1,600	80,000 (T)
8	1200			1,300	65,000 (T)
9	1200			1,300	65,000 (T)

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
10	70	1200	60,000	2,250	112,600 (T)
11	70	1100	55,000	2,225	111,300 (T)
12	70	900	45,000	2,275	113,800 (T)

"As Relaxed - 50 hours"

Test No.	Test Temp, °F	Preload, pounds	Preload, psi (1)	Ult. Load, pounds	Ult. Stress, psi
13	70	1000	50,000	2,100	105,100
14	70	950	47,500	2,310	115,600
15	70	1000	50,000	2,370	118,000

(1) Stress calculated at tensile stress area of .01999 square inches.
(T) Thread Failure
(N.S.) Nut Sheared

TABLE XLII (continued)

Part No. PP 200A-16

2. Double Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (2)
16	-423	8, 700	138, 500
17	-423	8, 900	141, 700
18	-423	9, 600	152, 800
19	70	5, 250	83, 600
20	70	5, 220	83, 100
21	70	5, 230	83, 200
22	1200	3, 625	57, 700
23	1200	3, 800	60, 500
24	1200	3, 900	62, 100

"As Cycled"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

25	70	5, 320	84, 700
26	70	5, 460	86, 900
27	70	5, 540	89, 600

"As Relaxed - 50 hours"

28	70	5, 550	88, 300
29	70	5, 680	90, 400
30	70	5, 620	89, 400

(2) Stress calculated at twice nominal diameter area, .06283 square inches.

TABLE XLII (continued)

Part No. PP 200A-16

3. Stress Relaxation @ 1200°F -

Initial Preload - 37,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress PSI (1)
31	10	450	27,500
32	10	500	25,000
33	10	650	32,500
34	50	1,000	50,000
35	50	950	47,500
36	50	1,000	50,000

(1) Stress calculated at tensile stress area of .01999 square inches.

APPENDIX IV

TEST RESULTS

RIVETS - PHASE II

TABLE XLIII

SUMMARY OF RESULTS

Semi-Blind Cherry Rivets
Materials - Al 2017-T4 & A-286

Test Temp.	Ultimate Strength Pounds						Shear Strength Pounds					
	Al 2017-T4			A-286			Al 2017-T4			A-286		
	1/8	5/32	3/16	1/8	5/32	3/16	1/8	5/32	3/16	1/8	5/32	3/16
-423°F	670	1320	1420	1200	1960	2400	880	1390	2000	1770	2940	4050
	580	1160	1400	1300	1820	2200	910	1400	1980	1800	2840	3960
	1160	920	1000	1000	2500	2600	900	1390	2200	1700	2800	3790
70°F	260	432	620	740	1200	1540	500	828	1300	1040	1620	2460
	252	400	630	760	1100	1420	500	832	1420	1070	1640	2440
	232	422	700	800	1260	1840	500	836	1240	1020	1980	2420
Max.	250°F			1200°F			250°F			1200°F		
	262	400	730	545	943	1290	480	745	1100	730	1200	1800
	228	475	650	617	1030	1340	490	730	1120	730	1210	1780
	232	434	695	612	916	1210	488	725	1150	830	1250	1830

TABLE XLIV

MECHANICAL PROPERTIES

Part No. CR-2162-4 Material Aluminum; 2017 T4 - Rivet, 7075 - Stem
Size 1/8 x 1/4" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	670	Blind head failure
2	-423	580	" " "
3	-423	1160	" " "
4	70	260	Blind head failure
5	70	252	" " "
6	70	232	" " "
7	250	262	Blind head failure
8	250	228	" " "
9	250	232	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

10	70	310	Blind head failure
11	70	285	" " "
12	70	280	" " "

TABLE XLIV (continued)

Part No. CR-2162-4

2. Single Shear

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	910	74,200
14	-423	880	71,700
15	-423	900	73,300
16	70	500	40,700
17	70	500	40,700
18	70	500	40,700
19	250	480	39,100
20	250	490	39,900
21	250	488	39,800

"As Cycled 12 Times"

70° F to -423° F to 70° F - cycling tests not conducted

70° F to 250° F to 70° F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
22	70	570	46,500
23	70	576	46,900
24	70	590	48,100

(1) Stress calculated at nominal diameter area of .01227 square inches.

TABLE XLIV (continued)

Part No. CR-2162-4

3. Stem Retention -

"As Received"

Test No.	Test Temp, °F	Push-Out Load, pounds
25	70	60
26	70	64
27	70	105

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

Test No.	Test Temp, °F	Push-Out Load, pounds
28	70	146
29	70	174
30	70	190

TABLE XLV

MECHANICAL PROPERTIES

Part No. CR-2162-5 Material Aluminum; 2017-T4 - Rivet, 7075 - Stem
Size 5/32 x 3/8" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	1,320	Blind head failure
2	-423	1,160	" " "
3	-423	920	" " "
4	70	432	Blind head failure
5	70	400	" " "
6	70	422	" " "
7	250	400	Blind head failure
8	250	475	" " "
9	250	434	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

10	70	435	Blind head failure
11	70	430	" " "
12	70	510	" " "

TABLE XLV (continued)

Part No. CR-2162-5

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	1,390	72,500
14	-423	1,400	73,000
15	-423	1,390	72,500
16	70	828	43,200
17	70	832	43,400
18	70	836	43,600
19	250	745	38,900
20	250	730	38,100
21	250	725	37,800

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

22	70	840	43,800
23	70	842	43,900
24	70	825	43,100

(1) Stress calculated at nominal diameter area of .01916 square inches.

TABLE XLV (continued)

Part No. CR-2162-5

3. Stem Retention -

"As Received"

Test No.	Test Temp, °F	Push-Out Load, pounds
25	70	240
26	70	220
27	70	280

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

Test No.	Test Temp, °F	Push-Out Load, pounds
28	70	450
29	70	320
30	70	360

TABLE XLVI

MECHANICAL PROPERTIES

Part No. CR-2162-6 Material Aluminum; 2017-T4-Rivet, 7075 - Stem
Size 3/16 x 3/8" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	1,420	Blind head failure
2	-423	1,400	" " "
3	-423	1,000	" " "
4	70	620	Blind head failure
5	70	630	" " "
6	70	700	" " "
7	250	730	Blind head failure
8	250	650	" " "
9	250	695	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

10	70	750	Blind head failure
11	70	790	" " "
12	70	700	" " "

TABLE XLVI (continued)

Part No. CR-2162-6

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	2000	72,500
14	-423	1980	71,700
15	-423	2200	79,700
16	70	1300	47,100
17	70	1420	51,400
18	70	1240	44,900
19	250	1100	39,900
20	250	1120	40,600
21	250	1150	41,700

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

22	70	1180	42,800
23	70	1220	44,200
24	70	1300	47,100

(1) Stress calculated at nominal diameter area of .02760 square inches.

TABLE XLVI (continued)

Part No. CR-2162-6

3. Stem Retention -

"As Received"

Test No.	Test Temp, °F	Push-Out Load, pounds
25	70	340
26	70	400
27	70	320

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

28	70	780
29	70	790
30	70	640

TABLE XLVII

MECHANICAL PROPERTIES

Part No. CR-2662-4 Material A-286; AMS 5735 - Rivet, AMS 5736 - Stem
Size 1/8 x 1/4" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	1200	Blind head failure
2	-423	1300	" " "
3	-423	1000	" " "
4	70	740	Manufactured head failure
5	70	760	Blind head failure
6	70	800	" " "
7	1200	545	Blind head failure
8	1200	617	" " "
9	1200	612	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

10	70	930	Manufactured head failure
11	70	960	" " "
12	70	946	" " "

TABLE XLVII (continued)

Part No. CR-2662-4

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	1770	144,500
14	-423	1800	147,000
15	-423	1700	138,500
16	70	1040	84,800
17	70	1070	87,200
18	70	1020	83,100
19	1200	730	59,500
20	1200	730	59,500
21	1200	810	66,000

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
22	70	1290	105,100
23	70	1240	101,100
24	70	1260	102,700

(1) Stress calculated at nominal diameter area of .01227 square inches.

TABLE XLVII (continued)

Part No. CR-2662-4

3. Stem Retention -

"As Received"

Test No.	Test Temp, °F	Push-Out Load, pounds
25	70	280
26	70	200
27	70	290

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Push-Out Load, pounds
28	70	670
29	70	620
30	70	690

TABLE XLVIII

MECHANICAL PROPERTIES

Part No. CR-2662-5 Material A-286; AMS 5735 - Rivet, AMS 5736 - Stem
Size 5/32 x 3/8" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	1960	Blind head failure
2	-423	1820	" " "
3	-423	2500	" " "
4	70	1200	Blind head failure
5	70	1100	" " "
6	70	1260	" " "
7	1200	943	Blind head failure
8	1200	1030	" " "
9	1200	960	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

10	70	1735	Manufactured head failure
11	70	1700	" " "
12	70	1690	" " "

TABLE XLVIII (continued)

Part No. CR-2662-5

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	2940	153,500
14	-423	2840	148,000
15	-423	2800	146,200
16	70	1620	84,600
17	70	1640	85,600
18	70	1980	103,300
19	1200	1200	62,600
20	1200	1210	63,200
21	1200	1250	65,200

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

22	70	2025	105,700
23	70	2000	104,400
24	70	1980	103,300

(1) Stress calculated at nominal diameter area of .01916 square inches.

TABLE XLVIII (continued)

Part No. CR-2662-5

3. Stem Retention -

"As Received"

Test No.	Test Temp, °F	Push-Out Load, pounds
25	70	380
26	70	400
27	70	340

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

Test No.	Test Temp, °F	Push-Out Load, pounds
28	70	800
29	70	1000
30	70	1100

TABLE XLIX

MECHANICAL PROPERTIES

Part No. CR-2662-6 Material A-286; AMS 5735 - Rivet, AMS 5736 - Stem.
Size 3/16 x 3/8" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	2600	Blind head failure
2	-423	2200	" " "
3	-423	2400	" " "
4	70	1540	Blind head failure
5	70	1420	" " "
6	70	1840	" " "
7	1200	1290	Blind head failure
8	1200	1340	" " "
9	1200	1210	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

10	70	2100	Manufactured head failure
11	70	2250	Blind head failure
12	70	2100	Manufactured head failure

TABLE XLIX (continued)

Part No. CR-2662-6

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	4050	147,000
14	-423	3960	143,500
15	-423	3790	137,500
16	70	2460	89,100
17	70	2440	88,400
18	70	2420	87,700
19	1200	1800	65,200
20	1200	1780	64,500
21	1200	1830	66,300

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 1200°F to 70°F

22	70	2950	106,900
23	70	2880	104,300
24	70	2980	108,000

(1) Stress calculated at nominal diameter area of .02760 square inches.

TABLE XLIX (continued)

Part No. CR-2662-6

3. Stem Retention -

"As Received"

Test No.	Test Temp, °F	Push-Out Load, pounds
25	70	520
26	70	500
27	70	580

"As Cycled 12 Times"

70° F to -423° F to 70° F - cycling tests not conducted

70° F to 1200° F to 70° F

Test No.	Test Temp, °F	Push-Out Load, pounds
28	70	1400
29	70	1850
30	70	1950

TABLE L

SUMMARY OF RESULTS

Solid Rivets per MS 20426
Materials - Al 2024-T4 & Pure Ti

Test Temp.	Ultimate Strength-Lbs.				Shear Strength-Lbs.			
	Al 2024-T4		Pure Ti		Al 2024-T4		Pure Ti	
	1/8	3/16	1/8	3/16	1/8	3/16	1/8	3/16
-423°F	1180	1800	720	1150	920	2420	1700	3870
	1100	1880	880	1100	1000	2500	1750	4160
	1080	1790	850	800	930	2600	1600	3720
70°F	660	1400	1340	2990	500	1300	1200	2620
	600	1360	1270	2900	500	1280	1240	2640
	660	1300	1360	2710	500	1240	1220	2490
Max.	250°F		500°F		250°F		500°F	
	705	1620	950	1700	500	1280	860	1600
	688	1500	970	1900	510	1300	780	1550
	685	1550	952	1700	500	1280	780	1600

TABLE LI

MECHANICAL PROPERTIES

Part No. MS 20426 Material Aluminum 2024-T4
Size 1/8 x 1/4" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	1180	Manufactured head failure
2	-423	1100	" " "
3	-423	1080	" " "
4	70	660	Manufactured head failure
5	70	600	" " "
6	70	660	" " "
7	250	705	Manufactured head failure
8	250	688	" " "
9	250	685	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

10	70	800	Manufactured head failure
11	70	800	" " "
12	70	800	" " "

TABLE LI (continued)

Part No. MS 20426 1/8 Aluminum

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	920	75,000
14	-423	1000	81,500
15	-423	930	75,700
16	70	500	40,800
17	70	500	40,800
18	70	500	40,800
19	250	500	40,800
20	250	510	41,600
21	250	500	40,800

"As Cycled 12 Times"

70° F to -423° F to 70° F - cycling tests not conducted

70° F to 250° F to 70° F

22	70	440	35,900
23	70	460	37,500
24	70	420	34,200

(1) Stress calculated at nominal diameter area of .01227 square inches.

TABLE LII

MECHANICAL PROPERTIES

Part No. MS 20426 Material Aluminum 2024-T4
Size 3/16 x 3/8" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	1800	Manufactured head failure
2	-423	1880	" " "
3	-423	1790	" " "
4	70	1400	Manufactured head failure
5	70	1360	" " "
6	70	1300	" " "
7	250	1620	Manufactured head failure
8	250	1500	" " "
9	250	1550	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

10	70	1600	Manufactured head failure
11	70	1600	" " "
12	70	1540	" " "

TABLE LII (continued)

Part No. MS 20426 3/16 Aluminum

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	2420	87,700
14	-423	2500	90,500
15	-423	2600	94,200
16	70	1300	47,100
17	70	1280	46,400
18	70	1240	44,900
19	250	1280	46,400
20	250	1300	47,100
21	250	1280	46,400

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 250°F to 70°F

22	70	1300	47,100
23	70	1280	46,400
24	70	1240	44,900

(1) Stress calculated at nominal diameter area of .02760 square inches.

TABLE LIII

MECHANICAL PROPERTIES

Part No. MS 20426 Material - Pure Titanium
Size 1/8 x 1/4" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	720	Manufactured head failure
2	-423	880	" " "
3	-423	850	" " "
4	70	1340	Manufactured head failure
5	70	1270	" " "
6	70	1360	" " "
7	500	950	Manufactured head failure
8	500	970	" " "
9	500	952	" " "

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 500°F to 70°F

10	70	1570	Manufactured head failure
11	70	1520	" " "
12	70	1480	" " "

TABLE LIII (continued)

Part No. MS 20426 1/8 Pure Titanium

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	1700	138,500
14	-423	1750	143,000
15	-423	1600	130,500
16	70	1200	97,800
17	70	1240	101,100
18	70	1220	99,400
19	500	863	70,300
20	500	784	63,900
21	500	772	62,900

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 500°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
22	70	1300	105,900
23	70	1240	101,100
24	70	1140	92,900

(1) Stress calculated at nominal diameter area of .01227 square inches.

TABLE LIV

MECHANICAL PROPERTIES

Part No. MS 20426 Material-Pure Titanium
Size 3/16 x 3/8" Grip

1. Tensile -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Location of Failure
1	-423	1150	Manufactured head failure
2	-423	1100	" " "
3	-423	800	" " "
4	70	2990	Manufactured head failure
5	70	2980	" " "
6	70	2710	" " "
7	500	1700	Body failure
8	500	1900	" "
9	500	1700	" "

"As Cycled 12 Times"

70°F to -423°F to 70°F- cycling tests not conducted

70°F to 500°F to 70°F

10	70	3025	Manufactured head failure
11	70	2990	" " "
12	70	2780	" " "

TABLE LIV (continued)

Part No. MS 20426 3/16 Pure Titanium

2. Single Shear -

"As Received"

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
13	-423	3,870	140,000
14	-423	4,160	151,000
15	-423	3,720	135,000
16	70	2,620	94,900
17	70	2,640	95,700
18	70	2,490	90,200
19	500	1,600	58,000
20	500	1,550	56,200
21	500	1,600	58,000

"As Cycled 12 Times"

70°F to -423°F to 70°F - cycling tests not conducted

70°F to 500°F to 70°F

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi (1)
22	70	2,980	108,000
23	70	2,900	105,100
24	70	2,800	101,400

(1) Stress calculated at nominal diameter area of .02760 square inches.

APPENDIX V

TEST RESULTS

POTENTIAL HIGH STRENGTH

FASTENER MATERIALS - PHASE IV

TABLE LV

SUMMARY OF RESULTS

MATERIALS - PHASE IV

MATERIAL PROPERTIES

Test Temp.	Ultimate Tensile Strength - KSI					(.2% Offset) Yield - KSI				
	Ti 1Al-8V-5Fe	U-212	Inco 718	Vasco Max. 300	25%C.R. Wasp.	Ti 1Al-8V-5Fe	U-212	Inco 718	Vasco Max. 300	25%C.R. Wasp.
-423°F	350.5	280.0	279.2	400.0	312.0	N.Y.	191.0	206.0	363.0	242.5
	306.5	275.0	278.0	425.0	316.0	N.Y.	187.5	205.0	392.0	255.0
	183.3	274.0	278.0	396.5	318.6	N.Y.	168.5	220.0	364.0	281.0
70°F	222.3	190.0	202.5	283.2	227.9	218.7	151.0	172.5	270.4	207.0
	213.1	192.5	202.0	281.3	226.0	212.6	149.0	167.5	276.0	202.0
	218.7	195.9	200.0	283.5	230.5	216.6	153.0		270.0	202.0
Max.	300°F	1200°F	1200°F	900°F	1400°F	300°F	1200°F	1200°F	900°F	1400°F
	193.6	145.0	164.7	199.0	154.5	189.4	121.0	144.1	192.7	152.0
	184.3	148.0	162.7	190.1	167.0	182.2	123.1	137.2	184.4	163.4
	193.8	146.0	166.0	193.4	164.7	186.2	122.5	141.0	188.7	152.6

Test Temp.	Elongation - %					Reduction of Area - %				
	Ti 1Al-8V-5Fe	U-212	Inco 718	Vasco Max. 300	25%C.R. Wasp.	Ti 1Al-8V-5Fe	U-212	Inco 718	Vasco Max. 300	25%C.R. Wasp.
-423°F	*	24.0	20.0	8.0	16.0	*	41.0	25.2	35.8	28.0
	*	22.0	20.0	7.0	20.0	*	35.0	31.0	30.5	29.5
	*	24.0	22.0	7.0	14.0	*	40.0	29.0	34.0	31.0
70°F	12.0	18.0	18.0	12.0	8.0	46.8	40.3	37.9	54.0	21.5
	8.0	18.0	20.0	13.0	12.0	17.1	40.3	39.4	51.9	28.0
	12.0	18.0	18.0	12.0	10.0	44.0	35.4	39.3	53.1	24.0
Max.	300°F	1200°F	1200°F	900°F	1400°F	300°F	1200°F	1200°F	900°F	1400°F
	18.0	24.0	16.0	13.0	6.0	60.5	46.0	23.1	62.5	12.0
	18.0	22.0	26.0	13.0	6.0	62.5	38.9	43.2	62.5	9.0
	16.0	20.0	20.0	12.0	8.0	54.0	42.0	40.8	58.5	9.0

V-Notch Properties (K_t 8)

Test Temp.	Ti-185		U-212		Inco 718		VM 300		25%C.R. Wasp.	
	KSI	Ratio	KSI	Ratio	KSI	Ratio	KSI	Ratio	KSI	Ratio
-423°F	68.6	.24	299.5	1.07	297.1	1.07	256.4	.63	340.0	1.08
	70.7	.25	309.5	1.12	299.1	1.08	255.4	.63	350.0	1.11
	64.0	.23	309.5	1.12	296.6	1.06	297.0	.73	337.0	1.07
70°F	240.4	1.12	246.4	1.28	260.3	1.28	387.8	1.37	308.0	1.35
	236.7	1.08	245.7	1.27	263.9	1.30	375.0	1.33	304.0	1.33
	239.6	1.10	246.9	1.28	261.1	1.29	378.7	1.34	312.0	1.37
Max.	300°F		1200°F		1200°F		900°F		1400°F	
	252.0	1.32	140.7	1.30	218.0	1.33	291.0	1.48	164.5	1.02
	250.7	1.31	195.9	1.34	215.0	1.31	292.9	1.49	150.0	.93
	250.3	1.31			200.0	1.22	296.1	1.50	148.0	.91

*Fractured Outside Gage

TABLE LVI

SUMMARY OF RESULTS

BOLTS - PHASE IV

BOLT PROPERTIES

Test Temp.	Ultimate Tensile Strength - KSI: Ti 1Al-8V-5Fe	U-212	Inco 718	Vasco Max.300	25%C.R. Wasp.	Johnson's 2/3 Approx. Yield Strength - KSI: Ti 1Al-8V-5Fe	U-212	Inco 718	Vasco Max.300	25%C.R. Wasp.
-423°F	111.9	223.8	225.5	327.7	307.9	N.Y.	178.7	215.8	281.6	244.7
	160.8	226.8	227.1	366.3	304.4	N.Y.	173.2	222.7	346.5	240.6
	162.2	225.5	233.2	354.0	313.4	N.Y.	181.5	222.7	340.3	247.5
70°F	221.3	187.0	198.0	272.3	242.0	213.0	132.0	160.8	241.3	178.0
	221.3	189.7	200.2	282.2	236.5	214.4	140.2	173.9	252.5	175.4
	229.5	188.3	196.0	280.9	244.7	221.3	141.6	178.7	247.5	178.7
	300°F	1200°F	1200°F	900°F	1400°F	300°F	1200°F	1200°F	900°F	1400°F
Max.	206.2	160.0	189.7	193.1	185.6	196.5	135.0	161.5	180.7	161.5
	213.0	157.0	192.4	185.6	167.7	203.4	138.0	162.2	172.6	144.4
	213.0	154.0	192.4	183.2	172.0	206.2	138.0	163.5	175.7	155.0

Shear Strength - KSI

Test Temp.	Ti-185	U-212	Inco 718	VM 300	25%Wasp.
-423°F	94.0	168.1	169.1	142.6	174.0
	118.5	166.0	173.2	127.3	169.0
	114.5	163.0	147.7	152.8	174.5
70°F	134.5	132.4	137.5	167.1	127.3
	135.5	132.4	138.5	168.1	127.3
	134.5	132.4	138.5	167.1	
	300°F	1200°F	1200°F	900°F	1400°F
Max.	105.9	90.7	105.9	116.1	104.4
	115.1	92.2	106.4	112.1	93.0
	115.1	95.8	104.9	114.1	96.8

N.Y. = No Yield

TABLE LVII

MECHANICAL PROPERTIES

Part No. EWB T20-4-38 Material Ti 1 Al-8V-5Fe (200 ksi)
Size 1/4-28 x 2.862

1. Tensile - Base Material Properties
(As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	350,500	No Yield	Fracture occurred	
2	-423	306,500	No Yield	outside gage	
3	-423	183,300	No Yield		
4	-320	294,700	No Yield	No ductility	
5	-320	175,800	No Yield	No ductility	
6	-320	144,300	No Yield	No ductility	
7	70	222,300	218,700	12.0	46.8
8	70	213,100	212,600	8.0	17.1
9	70	218,700	216,600	12.0	44.0
10	300	193,600	189,400	18.0	60.5
11	300	184,300	182,200	18.0	62.5
12	300	193,800	186,200	16.0	54.0

V-Notch Properties
(K_t 8)

Test No.	Test Temp, °F	Ultimate Load, pounds	Ult. Stress psi	Notch-to-Smooth Tensile Ratio
13	-423	1,700	68,600	0.24
14	-423	1,730	70,700	0.25
15	-423	1,600	64,000	0.23
16	-320	1,700	72,300	0.35
17	-320	1,700	72,600	0.35
18	-320	2,100	88,000	0.43
19	70	5,700	240,400	1.24
20	70	5,630	236,700	1.08
21	70	5,760	239,600	1.10
22	300	6,200	252,000	1.32
23	300	6,100	250,700	1.31
24	300	6,300	250,300	1.31

TABLE LVII (continued)

Part No. EWB T20-4-38

1. Tensile (continued) -

Bolt Properties*
(As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
25	-423	4,070	111,900	No yield	
26	-423	5,850	160,800	No yield	
27	-423	5,900	162,200	No yield	
28	-320	5,500	151,200	No yield	
29	-320	5,400	148,500	No yield	
30	-320	4,950	136,100	No yield	
31	70	8,050	221,300	7,750	213,000
32	70	8,050	221,300	7,800	214,400
33	70	8,350	229,500	8,050	221,300
34	300	7,500	206,200	7,150	196,500
35	300	7,750	213,000	7,400	203,400
36	300	7,750	213,000	7,500	206,200

2. Double Shear -

As Received

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
37	-423	9,200	94,000
38	-423	11,600	118,500
39	-423	11,200	114,500
40	70	13,200	134,500
41	70	13,300	135,500
42	70	13,200	134,500
43	300	10,400	105,900
44	300	11,300	115,100
45	300	11,300	115,100

*Tested with nut slugs of the same material and heat treatment.
(1) Stress calculated at Tensile Stress Area of .03637 square inches.
(2) Stress calculated at twice nominal dia. area, .09817 square inches.

TABLE LVII (continued)

Part No. EWB T20-4-38

3. Stress Rupture* -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
46	300	7,620	210,000	Failed Loading	
47	300	7,270	200,000	Failed Loading	
48	300	6,900	190,000	188.0	N.F.

4. Stress Relaxation @ 300° F

Initial Preload 160,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
49	1	5,520	151,700
	10	5,520	151,700
	50	5,420	149,000
50	1	5,450	150,000
	10	5,420	149,000
	50	5,350	147,100

5. Coefficient of Thermal Expansion

Coefficient of thermal expansion data is not available at the present time.

*Tested with nut slugs of the same material and heat treatment.
(1) Stress calculated at Tensile Stress Area of .03637 square inches.

TABLE LVIII

MECHANICAL PROPERTIES

Part No. EWB 1615-4-38 Material-U-212 (180 ksi)
Size 1/4-28 x 2.860

1. Tensile - Base Material Properties
(As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	280,000	191,000	24.0	41.0
2	-423	275,000	187,500	22.0	35.0
3	-423	274,000	168,500	24.0	40.0
4	70	190,000	151,000	18.0	40.3
5	70	192,500	149,000	18.0	40.3
6	70	195,900	153,000	18.0	35.4
7	1200	145,000	121,000	24.0	46.0
8	1200	148,400	123,100	22.0	38.9
9	1200	146,000	122,500	20.0	42.0

V-Notch Properties
(K_t 8)

Test No.	Test Temp, °F	Ultimate Load, pounds	Ult. Stress psi	Notch-to-Smooth Tensile Ratio
10	-423	7,120	299,500	1.07
11	-423	7,180	309,500	1.12
12	-423	7,180	309,500	1.12
13	70	5,830	246,400	1.28
14	70	5,740	245,700	1.27
15	70	5,800	246,900	1.28
16	1200	4,500	190,700	1.30
17	1200	4,550	195,900	1.34

TABLE LVIII (continued)

Part No. EWB 1615-4-38

1. Tensile (continued) -

Bolt Properties* (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
18	-423	8,140	233,800	6,500	178,700
19	-423	8,250	226,800	6,300	173,200
20	-423	8,200	225,500	6,600	181,500
21	70	6,800	187,000	4,800	132,000
22	70	6,900	189,700	5,100	140,200
23	70	6,850	188,300	5,150	141,600
24	1200	5,800	160,000	4,900	135,000
25	1200	5,700	157,000	5,000	138,000
26	1200	5,600	154,000	5,000	138,000

2. Double Shear -

As Received

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
27	-423	16,500	168,100
28	-423	16,300	166,000
29	-423	16,000	163,000
30	70	13,000	132,400
31	70	13,000	132,400
32	70	13,000	132,400
33	1200	8,900	90,700
34	1200	9,050	92,200
35	1200	9,400	95,800

*Tested with nut slugs of the same material and heat treatment.
(1) Stress calculated at Tensile Stress Area of .03637 square inches.
(2) Stress calculated at twice nominal dia. area, .09817 square inches.

TABLE LVIII (continued)

Part No. EWB 1615-4-38

3. Stress Rupture* -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
36	1200	4,910	135,000	1.1	T
37	1200	4,910	135,000	1.1	T
38	1200	4,546	125,000	10.6	T
39	1200	4,546	125,000	39.3	T
40	1200	4,546	125,000	55.4	T

4. Stress Relaxation @ 1200°F

Initial Preload 74,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
41	1	2,480	68,200
	10	2,320	63,200
	50	2,100	57,700
42	1	2,350	64,600
	10	2,200	60,500
	50	1,850	50,900

5. Coefficient of Thermal Expansion - (3)

Temperature, °F	Inches/Inch/°F X 10^6
200	9.1
400	9.3
600	9.4
800	9.55
1,000	9.8
1,200	10.1
1,400	10.55

*Tested with nut slugs of the same material and heat treatment.

(1) Stress calculated at Tensile Stress Area of .03637 square inches.

(3) Souce: JED - General Electric Material Property Data Book

TABLE LIX

MECHANICAL PROPERTIES

Part No. EWB 22-4-34 Material - Inconel 718 (180 ksi)
Size 1/4-28 x 2.625

1. Tensile -

Base Material Properties
(As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong, Gage, .5 in. %	Red. of Area, %
1	-423	279,200	206,000	20.0	25.2
2	-423	278,000	205,000	20.0	31.0
3	-423	278,000	220,000	22.0	29.0
4	70	202,500	172,500	18.0	37.9
5	70	202,000	167,500	20.0	39.4
6	70	200,000	--	18.0	39.3
7	1200	164,700	144,100	16.0	23.1
8	1200	162,700	137,200	26.0	43.2
9	1200	166,000	141,000	20.0	40.8

V-Notch Properties
(K_t 8)

Test No.	Test Temp, °F	Ultimate Load, pounds	Ult. Stress psi	Notch-to-Smooth Tensile Ratio
10	-423	7,100	297,100	1.07
11	-423	7,000	299,100	1.08
12	-423	6,940	296,600	1.06
13	70	6,080	260,300	1.28
14	70	6,150	263,900	1.30
15	70	6,070	261,100	1.29
16	1200	5,125	218,900	1.33
17	1200	5,050	215,000	1.31
18	1200	4,700	200,000	1.28

TABLE LIX (continued)

Part No. EWB 22-4-34

1. Tensile (continued) -

Bolt Properties* (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	-423	8,200	225,500	7,850	215,800
20	-423	8,260	227,100	8,100	222,700
21	-423	8,480	233,200	8,100	222,700
22	70	7,200	198,000	5,860	160,800
23	70	7,280	200,200	6,325	173,900
24	70	7,130	196,000	6,500	178,700
25	1200	6,900	189,700	5,875	161,500
26	1200	7,000	192,400	5,900	162,200
27	1200	7,000	192,400	5,950	163,500

2. Double Shear -

As Received

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
28	-423	16,600	169,100
29	-423	17,000	173,200
30	-423	14,500	147,700
31	70	13,500	137,500
32	70	13,600	138,500
33	70	13,600	138,500
34	1200	10,400	105,900
35	1200	10,450	106,400
36	1200	10,300	104,900

*Tested with nut slugs of the same material and heat treatment.
(1) Stress calculated at Tensile Stress Area of .03637 square inches.
(2) Stress calculated at twice nominal dia. area, .09817 square inches.

TABLE LIX (continued)

Part No. EWB 22-4-34

3. Stress Rupture* -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
37	1200	4,910	135,000	66.3	T
38	1200	5,274	145,000	25.0	T
39	1200	5,455	150,000	10.1	T
40	1200	5,455	150,000	16.4	T
41	1200	5,455	150,000	15.8	T

4. Stress Relaxation @ 1200°F

Initial Preload 99,000 psi

Test No.	Hours °F	Residual Stress pounds	Residual Stress psi(1)
42	1.0	3,200	88,000
	10.0	3,000	82,500
	50.0	2,400	66,000
43	1.0	3,100	85,200
	10.0	2,550	70,100
	50.0	2,100	57,700

5. Coefficient of Thermal Expansion - (3)

Temperature, °F	Inches/Inch/°F X 10^6
200	7.3
400	7.6
600	7.8
800	8.0
1,000	8.2
1,200	8.55
1,400	9.2
1,600	9.65

*Tested with nut slugs of the same material and heat treatment.
(1) Stress calculated at Tensile Stress Area of .03637 square inches.
(2) Source: JED General Electric Material Property Data Book.

TABLE LX

MECHANICAL PROPERTIES

Part No. EWB 926-4-28 Material Vasco Max 300 (260 ksi)
Size 1/4-28

1. Tensile -

Base Material Properties
(As Received)
.113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	400,000	363,000	8.0	35.8
2	-423	425,000	392,000	7.0	30.5
3	-423	396,500	364,000	7.0	34.0
4	70	283,700	270,400	12.0	54.0
5	70	281,300	276,000	13.0	51.9
6	70	283,500	270,100	12.0	53.1
7	900	199,000	192,700	13.0	62.5
8	900	190,100	184,400	13.0	62.5
9	900	193,400	188,700	12.0	58.5

V-Notch Properties
(K_t 8)

Test No.	Test Temp, °F	Ultimate Load, pounds	Ult. Stress psi	Notch-to-Smooth Tensile Ratio
10	-423	6,000	256,400	0.63
11	-423	5,950	255,400	0.63
12	-423	6,950	297,000	0.73
13	70	9,230	387,800	1.37
14	70	8,700	375,000	1.33
15	70	8,900	378,700	1.34
16	900	6,925	291,000	1.48
17	900	6,825	292,900	1.49
18	900	6,900	296,100	1.50

TABLE LX (continued)

Part No. EWB 926-4-28

1. Tensile (continued) -

Bolt Properties* (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	-423	13,200	326,700	11,375	281,600
20	-423	14,800	366,300	14,000	346,500
21	-423	14,300	354,000	13,750	340,300
22	70	11,000	272,300	9,750	241,300
23	70	11,400	282,200	10,200	252,500
24	70	11,350	280,900	10,000	247,500
25	900	7,800	193,100	7,300	180,700
26	900	7,500	185,600	6,975	172,600
27	900	7,400	183,200	7,100	175,700

2. Double Shear -

As Received

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
28	-423	14,000	142,600
29	-423	12,500	127,300
30	-423	15,000	152,800
31	70	16,400	167,100
32	70	16,500	168,100
33	70	16,400	167,100
34	900	11,400	116,100
35	900	11,000	112,100
36	900	11,200	114,100

*Tested with nut slugs of the same material and heat treatment.
(1) Stress calculated at Basic Pitch Dia. Area of .0404 square inches.
(2) Stress calculated at twice nominal dia. area, .09817 square inches.

TABLE LX (continued)

Part No. EWB 926-4-28

3. Stress Rupture* -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
37	900	6,928	170,000	31.3	T
38	900	6,928	170,000	22.8	T
39	900	6,928	170,000	17.7	T
40	900	7,070	175,000	6.1	T
41	900	7,070	175,000	4.7	T

4. Stress Relaxation @ 900°F

Initial Preload 101,500 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi (1)
42	1.0	3,300	81,700
	10.0	2,400	59,400
	50.0	1,535	38,000
43	1.0	3,200	79,200
	10.0	2,300	56,900
	50.0	1,500	37,100

5. Coefficient of Thermal Expansion - (3)

Temperature, °F	Inches/Inch/°F X 10^6
70 - 900	5.6

*Tested with nut slugs of the same material and heat treatment.
(1) Stress calculated at Tensile Stress Area of .0404 square inches.
(3) Aerospace Structural Metals Handbook.

TABLE LXI

MECHANICAL PROPERTIES

Part No. Stud - Material - Waspaloy (220 ksi)
Size 1/4-28

1. Tensile - Base Material Properties (As Received) .113 Specimens

Test No.	Test Temp, °F	Ult. Stress, psi	Yield Stress, psi	Elong. Gage, .5 in. %	Red. of Area, %
1	-423	312,000	242,500	16.0	28.0
2	-423	316,000	255,000	20.0	29.5
3	-423	318,600	281,000	14.0	31.0
4	70	227,900	207,000	8.0	21.5
5	70	226,000	202,000	12.0	28.0
6	70	230,500	202,000	10.0	24.0
7	1400	154,500	152,000	6.0	12.0
8	1400	167,000	163,400	6.0	9.0
9	1400	164,700	152,600	8.0	9.0

V-Notch Properties
(K_t 8)

Test No.	Test Temp, °F	Ultimate Load, pounds	Ult. Stress psi	Notch-to-Smooth Tensile Ratio
10	-423	8,150	340,000	1.08
11	-423	8,180	350,000	1.11
12	-423	7,850	337,000	1.07
13	70	7,160	308,000	1.35
14	70	7,170	304,000	1.33
15	70	7,260	312,000	1.37
16	1400	3,875	164,500	1.02
17	1400	3,500	150,000	0.93
18	1400	3,450	148,000	0.91

TABLE LXI (continued)

Part No. Stud Waspaloy (220 ksi)

1. Tensile (continued) -

Bolt Properties* (As Received)

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(1)	Yield Load, pounds	Yield Stress, psi
19	-423	11,200	307,900	8,900	244,700
20	-423	11,070	304,400	8,750	240,600
21	-423	11,400	313,400	9,000	247,500
22	70	8,800	242,000	6,475	178,000
23	70	8,600	236,500	6,380	175,400
24	70	8,900	244,700	6,500	178,700
25	1400	6,750	185,600	5,875	161,500
26	1400	6,100	167,700	5,250	144,400
27	1400	6,275	172,000	5,625	155,000

2. Double Shear -

As Received

Test No.	Test Temp, °F	Ult. Load, pounds	Ult. Stress, psi(2)
28	-423	17,000	174,000
29	-423	16,600	169,000
30	-423	17,100	174,500
31	70	12,500	127,300
32	70	12,500	127,300
33	1400	10,250	104,400
34	1400	9,125	93,000
35	1400	9,500	96,800

*Tested with nut slugs of the same material and heat treatment.
(1) Stress calculated at Tensile Stress Area of .03637 square inches.
(2) Stress calculated at twice nominal dia. area, .09817 square inches.

TABLE LXI (continued)

Part No. Stud Waspaloy (220 ksi)

3. Stress Rupture -

Test No.	Test Temp, °F	Load, pounds	Load Stress, psi(1)	Time, Hrs.	Location of Failure
36	1400	2,909	80,000	0.7	T
37	1400	2,545	70,000	5.2	T
38	1400	2,340	65,000	51.7	T
39	1400	2,340	65,000	85.8	T
40	1400	2,340	65,000	35.9	T

4. Stress Relaxation @ 1400° F

Initial Preload 108,300

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi(1)
41	1.0	2,360	64,900
	10.0	1,900	52,200
	50.0	1,250	34,400

5. Coefficient of Thermal Expansion - (3)

Temperature, °F	Inches/Inch/°FX10^6
200	6.8
400	7.1
600	7.3
800	7.5
1,000	7.7
1,200	8.0
1,400	8.5
1,500	8.8

(3) Source - JED- General Electric Material Property Data Book

(1) Stress calculated at Tensile Stress Area of .03637 square inches.